An investigation of diet selection as a technique for determining the ideal protein for growing pigs

Thesis

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AN INVESTIGATION OF DIET SELECTION AS A TECHNIQUE FOR DETERMINING THE IDEAL PROTEIN FOR GROWING PIGS.

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ABSTRACT

A series of dietary choice experiments was carried out to discover if growing pigs can discriminate between two feeds with differing amino acid concentrations and use this ability to select a mixture of the two feeds to meet their amino acid requirements. A protein dietary choice experiment was carried out to investigate the best experimental setup for future dietary choice experiments. Two similar dietary choice experiments were carried out with lysine and threonine, where pigs discriminated between two feeds with differing lysine or threonine concentrations. However, they did not select a mixture of two feeds, choosing to eat predominantly from one feed. Experiments with differing levels of lysine and threonine and protein and lysine showed similar results. Where some mixing did occur, the resulting protein concentrations selected were so diverse that they were unlikely to be a reflection of their protein requirements. Individual variation in the selections made may derive from a preference for a particular feeder. An experiment was carried out which determined feeder preference and discovered that this had no effect on selections made when a choice of feeds was offered. An experiment was carried out to dicover if the importance of tryptophan in the control of protein intake meant that its intake was more strictly regulated than that of lysine or threonine. Once again pigs discriminated between the feeds, but did not select a mixture of the two feeds. A final experiment discovered that pigs can supplement an amino acid deficient diet with a solution of that amino acid to allow them to grow as well as pigs on diets with excess amino acid. In conclusion, pigs can discriminate between two feeds with differing amino acid concentrations, but do not use this ability to select a mixture of two feeds to meet their requirements.

DECLARATION

This thesis was composed by the author and is a record of work carried out by her on an original line of research. All sources of information are shown in the texts and listed in the references; all help given by others is indicated in the acknowledgments.

None of this work has been presented in any previous application for a degree.

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Published Work

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FAIRLEY, R. A. C., ROSE, S. P. and FULLER, M.F. 1994. Selection of dietary tryptophan concentration by growing pigs. *Proceedings of the Nutrition Society* 53:199A

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1. Introduction

1.1. General Introduction

The amino acid composition of the diet of growing pigs is very important to their growth and development. For example pigs fed a diet with a low lysine concentration of 7.2 g kg^{-1} grew at only 70% of the growth rate of pigs fed a diet containing 8.7 g kg^{-1} lysine (Rogerson and Campbell, 1983), while pigs fed a low tryptophan diet grew less than 75% of the rate of pigs offered a higher tryptophan diet (Lenis, Diepen and Goedhart, 1990).

Despite understanding the need for accurate amino acid requirements, there is still no widespread agreement on the optimal concentrations of amino acids. The Agricultural Research Council (ARC, 1981) and the National Research Council (NRC, 1988) published markedly different recommended amino acid requirements (Table 1.1).

These differences could depend on many factors, such as the methods used to measure the requirements. The majority of experiments carried out to measure amino acid requirements are dose-response assays, which

TABLE 1.1. The Agricultural Research Council and the National Research Council recommended amino acid requirements for growing pigs.

	Concentration (g/kg Protein)	
	ARC (1981)	NRC (1988)
Lysine	70	50
Methionine + Cystine	35	27
Threonine	42	32
Tryptophan	10	8
Isoleucine	38	31
Leucine	70	40
Histidine	23	15
Phenylalanine + Tyrosine	67	44
Valine	49	32

offer varying concentrations of an amino acid and measure the response. The response parameters that are measured vary between experiments, the most common are growth and efficiency of feed utilisation (Schutte, Bosch, Lenis, Jong and Diepen, 1990), carcass quality (Rogerson and Campbell, 1982; Noblet, Henry and Dubois, 1987; Lenis *et al*, 1990; Lenis and Diepen, 1990) and nitrogen retention (Seve, 1983; Southern and Baker, 1983; Rosell and Zimmerman, 1985; Lewis and Peo, 1986). Even in the same experiment thcsc different measurements often indicate different optimal amino acid concentrations (Schutte *et al*, 1990). Differences may also occur between different groups of pigs. If the concentration of amino acid in the feed is measured, the optimal amount will differ between pigs of different ages, sexes and breeds as their requirement for protein differs. The NRC (1988) recommendations for amino acid requirements are expressed in this way, so this may account for some of the differences seen in Table 1.1.

Diet selection is a technique that has been used to allow pigs to select a diet to meet their requirements from a choice of feeds. Early studies gave a free choice of a number of feed ingredients, and this resulted in increased growth rates (Evvard, 1915). More recent work has concentrated on providing a choice two feeds that differ in only one nutrient, usually protein, to allow growing pigs to determine the protein concentration of their diet (Kyriazakis, Emmans and Whittemore, 1990; Bradford and Gous, 1991a).

The general objective of this project was to discover how growing pigs respond to a choice between feeds that differ only in the concentration of a single amino acid.

The specific objectives of this project were:

1. a) To investigate whether growing pigs will discriminate between two feeds that differ only in the concentration of a single amino acid.

b) To discover whether growing pigs will select a mixture of two feeds that differ only in the concentration of a single amino acid, to meet their amino acid requirements.

2. To examine possible explanations for pigs not selecting a mixture of two feeds in the single amino acid experiments.

3. To explore an alternative method of diet selection by providing the pigs with supplemental amino acids in solution.

1.2. Amino Acid Biochemistry

This chapter is not intended as a review of current research on amino acid biochemistry, as that is outside the scope of this project. It is intended as a background for amino acid nutrition. All facts that are not specifically referenced came from Stryer (1988) and Bender (1985) and these two books provide a more in depth coverage of the subject.

Amino acids are the basic units of proteins. There are about twenty amino acids present in proteins, each with a different side chain. All proteins are constructed from these amino acids. Amino acids consist of an amino group (NH_2), a carboxyl group (COOH), a hydrogen atom and a distinctive side chain bonded to the α-carbon atom.

$$
\begin{array}{lccc}
 & NH_2 & & NH_3^+ \\
 & | & & | \\
R = \text{Side} & H - C - COOH & & H - C - COO^- \\
\quad \text{Chain} & | & & | \\
 & R & & R
\end{array}
$$

un-ionized form | Dipolar ion (zwitterion)

At neutral pH amino acids in solution are predominantly dipolar ions. The degree of ionization changes at different pH.

The twenty amino acids can be classed into six groups according to the structure of their side chains.

(i) Aliphatic amino acids - glycine, alanine, valine, leucine, isoleucine and proline.

(ii) Aromatic amino acids - phenylalanine, tryptophan and tyrosine.

(iii) Sulphur amino acids - methionine and cysteine.

(iv) Hydroxyl amino acids - serine and threonine.

(v) Basic Amino acids - arginine, lysine and histidine.

(vi) Acidic amino acids - asparagine, aspartate, glutamate and glutamine.

Pigs can make only nine of the twenty amino acids. Those amino acids that cannot be made must be obtained from food. The amino acids that cannot be made are called essential amino acids, whereas the amino acids that can be made are termed non-essential. The essential amino acids for pigs are histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan and valine. Of the eleven non-essential amino acids in pigs two, cysteine and tyrosine, are made from methionine and phenylalanine, respectively, which are essential, so they can be considered semi-essential. Arginine is produced in the urea cycle, so can also be considered semi-essential. In humans this amount of arginine is sufficient for adult growth, but not for children, in growing pigs enough arginine is produced to allow growth at two thirds of the normal rate (ARC, 1981).

Amino Acid Degradation

Proteins and amino acids present in excess of needs cannot be stored. All proteins are degraded to amino acids by proteases, and excess amino acids are degraded by specific oxidative enzymes. The resulting carbon skeletons are utilised in metabolic pathways.

1. Deamination. The ammonium ions produced through deamination are highly toxic, so must be got rid of quickly. In mammals ammonia is converted to urea which is very soluble and is excreted in urine. The major site of amino acid degradation in mammals is the liver. The α-

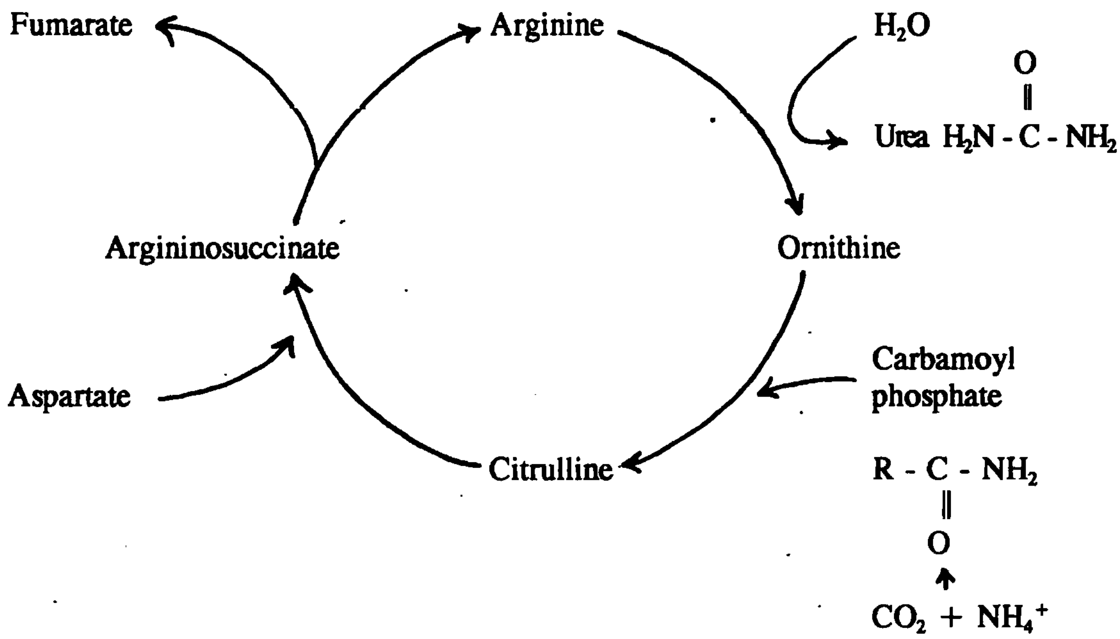
amino group of many amino acids is transferred to α-keto-glutarate to form glutamate which is oxidatively deaminated to yield NH_4^+.

e.g. Aspartate + α-keto-glutarate $\leftrightarrow$ oxaloacetate + glutamate

Serine and threonine can be directly deaminated, because they have a hydroxyl group. Serine loses a hydrogen atom from its α-carbon and a hydroxyl group from its ß-carbon atom to yield aminoacrylate. This unstable compound reacts with H_2O to give pyruvate and NH_4^+.

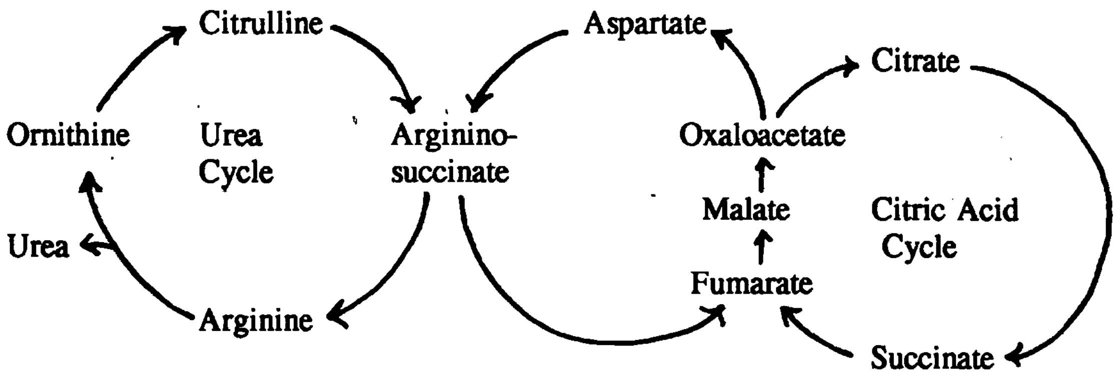
Some of the ammonium ions produced in the breakdown of amino acids are consumed in the biosynthesis of nitrogen compounds. The excess ammonium ions are converted into urea by the urea cycle. NH_4^+ combines with CO_2, ATP and H_2O to form carbamoyl phosphate. The carbamoyl group is transferred to ornithine to form citrulline. Citrulline then condenses with aspartate, which provides the other nitrogen atom for urea, to form argininosuccinate. Argininosuccinase then cleaves argininosuccinate to form fumarate and arginine. Arginine is hydrolysed to urea and ornithine.

<u>The Urea Cycle</u>



The formation of NH_4^+, its incorporation into carbamoyl phosphate and the subsequent synthesis of citrulline occur in the mitochondrial matrix. In contrast the next three reactions of the urea cycle, which lead to the formation of urea, take place in the cytosol.

The urea cycle is linked to the citric acid cycle by fumarate. Fumarate is hydrated to malate, which is in turn oxidised to oxaloacetate. Oxaloacetate can then be transaminated to aspartate or can be condensed with acetyl CoA to form citrate. Oxaloacetate can also be either converted into glucose by the gluconeogenic pathway or converted to pyruvate.



2. Fate of Carbon Skeletons. The strategy of amino acid degradation is to form major metabolic intermediates that can be converted into glucose or be oxidised by the citric acid cycle. The carbon skeletons of the twenty amino acids are degraded into only seven molecules: pyruvate, acetyl CoA, acetoacetyl CoA, α-keto-glutarate, succinyl CoA, fumarate and oxaloacetate.

Amino acids that are degraded to acetyl CoA or acetoacetyl CoA are called ketogenic, because they give rise to ketone bodies. Amino acids that are degraded to pyruvate, α-keto-glutarate, succinyl CoA, fumarate and oxaloacetate are called glucogenic. Net glucose synthesis is possible because these are citric acid intermediates and pyruvate can be converted into phosphoenol-pyruvate and then into glucose. Mammals lack a pathway for the synthesis of glucose from acetyl CoA or acetoacetyl CoA.

Lysine is a ketogenic amino acid which is ultimately converted to acetoacetyl CoA. This can occur via two distinct pathways.

Lysine → Saccharopine → α-Aminoadipic δ-Semialdehyde

Lysine → ϵ-Acetyllysine
↓
ϵ-Acetoamide α-ketocaproicacid
↓
ϵ-Amino-α-keto caproic acid
↓
Pipecolic Acid → α-Aminoadipic δ-Semialdehyde

α-Aminoadipic δ-Semialdehyde
↓
α-Aminoadipic Acid
↓
α-Ketoadipic Acid
↓
Glutaryl CoA
↓
Glutaconyl CoA
↓
Crotonyl CoA
↓
ß-Hydroxybutyryl
↓
Acetacetyl CoA
↓
Acetyl CoA

Lysine condenses with α-keto-glutarate and is reduced to form saccharopine, which is cleaved to release glutamate and the semialdehyde of 2-aminoadipate. The semialdehyde is oxidised to form 2-aminoadipate, which can be transaminated to 2-ketoadipate which can be converted to crotonyl CoA. In mammals lysine is degraded by way of saccharopine in the liver, but the pipecoloic acid pathway may be the major route of lysine catabolism in the brain. It has also been suggested that lysine can be catabolised to form homocitrulline and homoarginine (Ryan and Wells, 1966).

Threonine can be directly deaminated by threonine dehydratase as mentioned above:

$$\text{Threonine} \rightarrow \alpha\text{-Ketobutyrate} + NH_4^+$$

The α-ketobutyrate molecule formed is oxidatively decarboxylated to form propionyl CoA, which eventually becomes oxaloacetic acid, an intermediate in the citric acid cycle (McGilvery and Goldstein, 1983). Threonine can also be degraded by a dehydrogenase reaction to form glycine and acetyl CoA. This means that threonine is both glucogenic and ketogenic (McGilvery and Goldstein, 1983).

Three carbon atoms of **tryptophan** emerge in alanine (which is converted to pyruvate), one in formate and four as crotonyl CoA, which is derived from α-ketoadipic acid and follows the same degradation pathway as lysine (McGilvery and Goldstein, 1983).

1.3. Amino acid requirements of growing pigs.

The amino acid requirements of pigs can be described in several different ways. Often, amino acid requirements are described as a concentration of the diet provided (NRC, 1988). The recommended concentration will change with the age of the pig, and the related change in the recommended crude protein concentration. The NRC (1988) recommended five different amino acid concentrations depending on the live-weight of the pig. Another common method of describing amino acid requirements is as a daily amount. The ARC (1981) used this method, but once again the daily amount will change with age and protein concentration. The ARC (1981) also described the amino acid requirements of growing pigs as a proportion of protein, known as ideal protein.

1.3.1. Ideal Protein

An ideal protein has been defined as one which supplies the optimal balance of amino acids for growth and maintenance (Cole, 1979). Pigs require amino acids in a certain ratio, which is determined by their requirements for growth and maintenance. The concept is based on the assumption that the ratio of amino acids required to deposit lean tissue will be the same for all pigs, regardless of age, weight, breed or sex, so that the ideal protein for growth will be the same for all pigs (Cole, 1979). The balance of amino acids required for maintenance is different to that required for growth, so there are slight differences in the overall ideal protein as the proportion of amino acids used for maintenance and growth changes.

There have not been any experiments to examine the optimal amino acid requirements of pigs at different crude protein concentrations. However, it has been shown that the optimal lysine requirement of chickens remains the same, when expressed as a proportion of protein, but not as a proportion of the diet, at different protein concentrations (Morris, Al-Azzawi, Gous and Simpson, 1987; Surisdiarto and Farrell, 1991).

The ARC (1981) expressed the amino acid requirements of growing pigs as their ratio to protein. This ratio was determined from dose-response experiments and where information was scarce from the ratios of amino acids to protein in pig tissue. Since then there have been several studies which have investigated the balance of amino acids. The results of some of these studies are shown in Table 1.2, and it can be seen that while

TABLE 1.2. Proposed balances of amino acids in the ideal protein for growing pigs.

	Recommended balance of amino acids (g/kg protein)						
	Agricultural Research Council (1981)	Moughan & Smith (1984)	Zhang *et al* (1984)	Fuller *et al* (1989)	Wang & Fuller (1989)	Wang & Fuller (1990)	Chung & Baker (1992)
Lysine	70	80	72	59	65	65	54
Methionine				16			16
Methionine + Cysteine	35	43	34	35	41	39	32
Threonine	42	47	44	44	47	43	35
Tryptophan	10	10	14	11	12	12	10
Isoleucine	38	37	37	36	39	39	32
Leucine	70	71	68	65	72	72	54
Histidine	23	27	23			25	17
Phenylalanine				35			27
Phenylalanine + Tyrosine	67	80	85	72	78	78	51
Valine	49	53	45	44	49	49	37
Arginine			58				22
Total Essential Amino Acids	404	448	480	366	403	422	344
Non Essential Amino Acids	596	552	520	634	597	578	656

there is a broad agreement on the optimum balance, there is still a great deal of variation in the recommendations for individual amino acid proportions.

The differences between the optimal balance of amino acids for maintenance and growth have been investigated by feeding a range of amino acid concentrations, and plotting protein accretion against amino acid intake (Fuller, McWilliam, Wang and Giles, 1989). The slope of the resultant regression line indicated the requirement of that amino acid for growth while the intercept indicated the requirement for maintenance. Table 1.3 shows the ratios of the different ideal balances for growth and maintenance. Greater proportions of threonine, tryptophan and methionine plus cystine are required relative to lysine for maintenance; and isoleucine, leucine, valine and phenylalanine plus tyrosine are required in smaller proportions relative to lysine. Despite these differences, however, in a later experiment which looked at the overall ideal protein at different planes of nutrition, where the ratio between growth and maintenance should differ, Wang and Fuller (1990) found no differences between the ideal protein at the different planes of nutrition.

TABLE 1.3. Ratios of essential amino acids in the ideal protein for protein accretion and maintenance (taken from Wang and Fuller, 1990)

	Ratio of Amino Acids in Ideal Balance	
	Protein Accretion	Maintenance
Lysine	100	100
Methionine + Cystine	53	136
Threonine	69	147
Tryptophan	18	31
Isoleucine	63	44
Leucine	115	64
Phenylalanine + Tyrosine	124	103
Valine	77	56

1.3.2. Methods used to determine amino acid requirements of growing pigs.

(i) Analysis of Body Tissue. The amino acid ratio of pig tissue has been used to determine the balance of amino acids in an ideal protein, as the primary function of dietary amino acids is to form body proteins. This approach was used by the ARC (1981) in formulating their ideal balance of amino acids. However, Chung and Baker (1992) discourage this practice because of the variable turnover rates of individual amino acids. It is also possible that the amino acid composition of the whole body changes over time. Kyriazakis and Emmans (1993b) examined this idea and found that there was a systematic change in amino acid composition as a function of body weight.

(ii) Dose-Response Experiments. The main approach to measuring amino acid requirements is the dose-response experiment, where pigs are given varying concentrations of a single amino acid and the requirement is determined as the concentration at which a maximal response is obtained. There are many responses which can be measured, the simplest being growth and efficiency of feed utilisation (Schutte *et al*, 1990). Most recent studies have combined growth and feed intake measurements with other characteristics such as carcass quality (Rogerson and Campbell, 1982; Noblet *et al*, 1987; Lenis *et al*, 1990; Lenis and Diepen, 1990) or nitrogen retention (Seve, 1983; Southern and Baker, 1983; Rosell and Zimmerman, 1985; Lewis and Peo, 1986). The plasma concentration of a specific amino acid should not increase until that amino acid is present in the diet in excess of requirements. Plasma amino acid concentrations, therefore, are often measured in dose-response experiments, this is frequently carried out with plasma urea measurements (Taylor, Cole and Lewis, 1982, 1983 and 1985; Seve, 1983; Southern and Baker, 1983; Rosell and Zimmerman, 1985; Lewis and Peo, 1986). Oxidation of an amino acid occurs when that amino acid is present in excess of needs, and this can be measured directly if the amino acid is labelled with ^{14}C. Oxidation of an indicator amino acid can also be measured to give a reasonably accurate requirement for other amino acids. This technique has been used to measure amino acid requirements, especially in very young pigs where the time span does not allow accurate growth measurements (Kim and Bayley,1983; Kim, Elliott and Bayley, 1983; Kim, McMillan and Bayley, 1983; Lin, Smith and Bayley, 1986).

(iii) Deletion of a single amino acid. Wang and Fuller (1989) estimated the balance of amino acids in an ideal protein using a method of amino acid deletion. It was based on the fact that the removal of a non-limiting amino acid has no effect on nitrogen retention, until that amino acid becomes limiting. Using this principle they fed a series of diets that had 20% of each essential amino acid removed. From the resulting nitrogen retention data they were able to calculate a balance of amino acids in the ideal protein.

1.4. Diet Selection

In order to survive, animals must be capable of satisfying their nutrient requirements for growth, maintenance and reproduction by selecting a diet from available food sources. Research in this area suggests that, as well as satisfying their requirements, wild animals are capable of optimising their food intake, especially in respect of energy intake (Lea, 1979).

The earliest research carried out on the diet selection of pigs involved allowing a free choice of diet from a number of different feeds. Evvard (1915) offered pigs between seven and nine feeds, including water and minerals as well as cereal and protein sources, and allowed the animals to choose their own diets. This resulted in increased growth rates, with some of the pigs growing faster than any previously recorded at the Iowa Agricultural Station. At the start of this trial the pigs tended to eat relatively high concentrations of protein concentrates, and this declined as the pigs grew and required less protein.

In 1967, Braude reviewed choice feeding as a method of feeding and concluded that growth rates seldom equalled, let alone surpassed, those of single fed pigs. Most of the trials reviewed offered the pigs a choice of a cereal and a protein supplement, and many found that single fed pigs had better results (Brown, 1956; Adams and Ward, 1957; Hutchison, Terrill, Jensen, Becker and Norton, 1957), most of the remaining experiments reviewed found no difference between single or choice-fed pigs (Thrasher, Mullins and Newman, 1961; Rerat and Henry, 1964; Holck and Tribble, 1965).

1.4.1. Selection of Protein Concentration

More recent work has tended to concentrate on the diet selections made when pigs are offered two diets that differ in only one respect. Extensive work has been carried out recently in Edinburgh on diet selection of crude protein level in pigs. When singly housed pigs are offered feeds similar in all respects, except crude protein level, it was concluded that they can select a balance of the feeds that reflects their requirements for protein (Kyriazakis, Emmans and Whittemore, 1987; Kyriazakis *et al*, 1990), provided that the feeds offered did not restrict the pig's selection (Kyriazakis and Emmans, 1989). The crude protein level selected by the pigs at Edinburgh tended to be around 205 g kg feed^{-1} for 12-30 kg pigs, and the level selected decreased over time (Kyriazakis *et al*, 1990).

Additional treatments were carried out with pigs fed the single feeds used, to gain an idea of pig performance on the feeds used. Of these single-fed pigs the best growth rate occurred on the feed with a crude protein level of 217 g kg feed^{-1}, but this was less than the growth rate of most of the choice-fed pigs.

Pigs were only capable of selecting their requirements if one of the feeds offered was above and the other feed was below their requirements. If both feeds were below the requirements, the pigs ate mainly the least limiting feed, but continued to sample from the other feed. However, if both feeds were above the requirements, the pigs ate the feed with the lowest excess (Kyriazakis, Emmans and Whittemore, 1989).

1.4.2. Training Period

Allowing pigs to experience feeds prior to the selection period improved the ability of the pigs to select an appropriate diet, if both feeds were offered for alternative 24 hour periods for six days (Kyriazakis, Emmans and Whittemore, 1988). The diet selections of pigs were not affected by the position of the two feeders. Changing the positions of the feeders in the middle of a trial did not affect the diets selected by the pigs, but some pigs took a few days to respond to a change of position (Kyriazakis *et al*, 1990). This suggests that pigs use the position of the feeders as a cue to the nutrient composition of the feed inside, but are constantly updating this information from some physiological response to the feed eaten.

Bradford and Gous (1991a), carried out some similar work with group housed pigs, offering them a choice of feeds differing only in crude protein content and with a training period of eight days. They concluded that pigs could differentiate between feeds differing in protein content and select a balance of the two feeds to meet their changing requirements. However, it is not possible to determine an individual pig's feed selection when it is housed in a group, so it is not possible to tell whether individuals were making daily selections.

Adding an anti-nutritive ingredient, such as rapeseed meal, affects the outcome of diet selections if it is present in only one of the feeds offered (Kyriazakis and Emmans, 1992). Where one feed contained rapeseed and the other feed offered did not, the pigs chose the feed without rapeseed added, regardless of the protein contents of the two feeds offered. When both feeds contained rapeseed meal, the pigs made selections according to their protein requirement. The included level of rapeseed meal had no effect on performance when fed as a single feed.

1.4.3. Commercial Applications of Diet Selection

Selection of dietary crude protein content has been investigated as a commercial feeding system, since evidence from singly housed pigs suggests that choice-fed pigs grow at a similar or better rate than single-fed pigs. Only two feeds need to be formulated for the entire growing period and this would allow protein to be used more efficiently than present systems. Bradford and Gous (1991b) directly compare choice feeding systems with phase feeding (feeding a number of feeds with sequentially lower protein contents to try and match changing requirements) and single feeding systems. They found that phase feeding improved feed conversion efficiency and caused a decline in feed intake and P2 backfat thickness, and these effects grew with the number of phases in the system. Choice feeding was not significantly different from either phase feeding or single feeding. Phase feeding requires more different feeds than free choice feeding. Kyriazakis and Emmans (1989) suggest choice feeding could be used where growth and fattening characteristics need to be observed, such as in selection stock, and where the fatness desired by the animal is no more than that desired by the farmer, such as in young pigs or boars. An experiment with weaned piglets offered a choice of diets with differing protein and energy concentrations reported that providing a choice of diets reduced feed costs by 20% (Dams, Edwards, Tibble, Toplis and Close, 1994a and b).

Other studies on the commercial viability of diet selection have had less success. When pigs were offered a choice between a grower and a finisher feed, they had a marked preference for the grower feed, which resulted in increased fatness and feed costs (Gill, Sanchez-Serrano, English, Robledo and Roden, 1994). Early weaned piglets fed either a high cost diet, a low cost diet or a low cost diet with a choice of supplement, performed better on the two single diets than on any of the choices offered (Gill, Robledo, English and Sanchez-Serrano, 1994). In a series of experiments on weaner piglets and grower/finisher pigs, Close (1994, personal communication) concluded that the choices made by pigs tend to be inconsistent.

1.4.4. Selection of Amino Acid Concentration

Pigs can not only differentiate between the quantities of protein in feeds, but also appear to be able to differentiate between proteins of different quality. Pigs offered a choice between a protein-free diet and casein or casein supplemented with synthetic methionine (the first limiting amino acid in casein), tended to avoid the protein-free feed in preference for either casein alone or the supplemented casein. The supplemented casein, however, was preferred to the unsupplemented casein (Robinson,1975). Henry (1985) describes an earlier experiment where pigs were offered a similar choice between a protein-free feed and a feed with a set level of protein, and were unable to select protein at a level optimal for growth.

Pigs offered a choice between a lysine-deficient feed and the same feed with supplemental lysine showed a slight preference for the supplemented feed (Robinson, 1975). Devilat, Pond and Miller (1970) offered pigs the choice between a complete diet and a diet deficient in some amino acids, and the pigs ate mainly the complete diet. When offered a choice of diets with an additional 4% of synthetic amino acids, pigs had a definite order of preference with an excess of threonine being the most acceptable, then lysine, arginine, methionine and tryptophan (Edmonds *et al*, 1987). Henry (1987), found that, while some selection occurred when pigs were offered diets that differed only in their lysine content, it was not constant throughout the different treatments. This is probably because many of the choices were limiting, offering two feeds both below the requirements for lysine (70 g kg protein^{-1}, ARC, 1981). The results also changed from week to week as feeder position was changed, thus the pigs were prevented from using this as a cue for feed quality. Another experiment with weanling pigs offered a choice of feeds with different lysine concentrations showed a great deal of variation in individual intakes of each feed. Half these pigs had no training period, and the other half had six days alternate access to the feeds, so this may explain some of the variation (Dalby, Varley, Forbes and Jagger, 1994).

Chicks offered a choice of feeds with either adequate or deficient lysine were able to select a mixture of the two feeds that allowed them to grow at up to 77% of the rate of chicks fed only the adequate lysine feed (Newman and Sands, 1983). When offered a choice of diets with 4% excesses of amino acids, chickens preferred an excess of lysine to an excess of methionine, threonine or arginine, while an excess of tryptophan was preferred least (Edmonds and Baker, 1987). Captive White-crowned Sparrows have also shown an ability to select an adequate diet for moulting from two feeds differing in sulphur amino acids (Murphy and King, 1987), and can maintain their body weight or restore lost weight when offered a choice of feeds with differing lysine or valine concentrations (Murphy and King, 1988).

Laboratory rats appear to be able to regulate their intakes of single amino acids when offered a choice of two foods that differ in amino acid composition. When rats were offered a choice of feeds that consisted of a casein diet and a diet with an amino acid mixture that was deficient in lysine and methionine they were able to regulate their intake of both amino acids, although the intake of methionine was more tightly regulated than that of lysine (Muramatsu and Ishida, 1982). Rats were also capable of regulating lysine intake when offered two foods both based on gluten but with different lysine contents (Muramatsu and Ohya, 1982). Rats also appear to be able to regulate their intakes of phenylalanine (Yamamoto, Makita and Muramatsu, 1984), threonine (Yamamoto, Suzuki and Muramatsu, 1985) valine, leucine and isoleucine (Yamamoto and Muramatsu, 1987a) and histidine and arginine (Yamamoto and Muramatsu, 1987b). Although the intake of these amino acids was regulated by individual rats to allow a normal growth rate, there was a great deal of individual variation in the daily intake.

1.4.5. Sensory Properties of Feed

Pigs do not appear to make selections based on the taste of feeds. When weanling pigs were offered two feeds differing in lysine concentration, their selections were the same whether or not one of the feeds was presented with an additional flavour (Dalby *et al*, 1994). Laboratory rats also do not select their diet on taste. If quinine is present in a balanced food they will eat it in preference to a food with added saccharin that is imbalanced despite the fact they prefer saccharin to quinine at other times (Larson *et al*, 1971). Rats which had impaired taste from gustatory deafferation were still able to select a balanced diet, although this diet was different from the diet of control rats, the treated rats having a reduced preference for saccharin (Miller and Teates, 1986).

1.4.6. Diet Selection Can Reflect Physiological State

Pigs are able to compensate for previous underfeeding of protein if they are given a choice of feeds differing in protein concentration (Kyriazakis and Emmans, 1991). Pigs fed a low protein feed until they reached 16 kg liveweight had more lipid and a lower body protein:ash ratio than pigs fed a high protein feed. when these pigs were then given a choice between the high and low protein feeds (with a six day training period first), the pigs previously fed the low protein feed selected a higher level of protein, grew faster, had a higher feed intake and were more efficient than those previously fed the high protein feed. At 33 kg the lipid weights were similar for both sets of pigs. Rats are also able to make choices to reflect their physiological state, for instance pregnant and lactating rats increased their protein consumption (Leshner, Seigel and Collier, 1972); pancreatectomized rats, that had previously shown diabetic symptoms, increased fat and protein intakes and decreased carbohydrate intake (Richter and Schmidt, 1941).

2. Experiments

2.1. Selection of dietary protein concentration by growing pigs.

2.1.1. Introduction

Recent work has shown that growing pigs, when offered a choice of two feeds with different protein concentrations can select a balance of the two feeds which meets their protein requirements. The two feeds should be similar in all other respects and the choices offered should be non-limiting (Emmans,1991), to allow the pigs to select their protein requirement. Performance of these choice-fed pigs is no different to that of pigs fed on only one of the feeds, and the protein concentration selected decreases with time, as the relative requirements for growth and maintenance change (Kyriazakis, Emmans and Whittemore, 1990, Bradford and Gous, 1991).

The present experiment was conducted to investigate this ability of pigs to discriminate between feeds which differed in protein concentration, and to discover if they could select a mixture of the two feeds that met their protein requirements. Previous work has been carried out on pigs housed singly (Kyriazakis *et al*, 1990) and on pigs housed in groups (Bradford and Gous,1991), and this experiment looked at both these housing options to discover if they have any effect on the diets selected. The feed was presented as either meal or pellets to discover if this had any effect on the diets selected.

2.1.2. Methods and Materials

A diet selection experiment was conducted at the experimental pig house, Harper Adams Agricultural College, Shropshire. Six (3 x 2) dietary treatments were used: three choice-feeding treatments consisting of a choice between a high and a low protein feed and two forms of feed presentation (pellets and meal). Half the house was used for singly penned pigs and half for groups of three pigs. Forty eight male pigs, approximately seven weeks old and with a mean weight of 15.3 kg, were allocated at random to pens, with either one pig or three pigs per pen. The house was filled over two weeks (24 pigs each week) and these were considered as two time blocks.

The three dietary choices provided were:

1. High Protein (225 g kg^{-1}) + Low Protein (98 g kg^{-1})
2. High Protein (225 g kg^{-1}) + Medium Low Protein (140 g kg^{-1})
3. Medium High Protein (178 g kg^{-1}) + Low Protein (98 g kg^{-1})

The two basal feeds were formulated to contain 98 g protein kg^{-1} (low protein), and 225 g protein kg^{-1} (high protein). The composition of these two feeds is shown in Table 2.1. Two intermediate feeds (140 g and 178 g protein kg^{-1}, medium low and medium high protein respectively) were made by appropriate blending of the two basal feeds. The feeds used were based on those used by Bradford and Gous (1991) in a similar experiment.

All the pens were in the same house. Where there were three pigs in a pen, each pen was equipped with two single space feeders with nipple drinkers allowing *ad libitum* access to feed and water. The singly penned pigs were provided with troughs for feed and water, and *ad libitum* access to both feed and water was available (Figure 2.1).

Dietary treatments were allocated randomly to pens in each block and the feeds were allocated at random to one of the two feeders in each pen. All pigs were weighed at the start of the experiment, after the initial training period and then fortnightly. Feed consumed was recorded at the same times and, additionally, half-way through the initial training period. Weight and feed intake means for each pen were calculated.

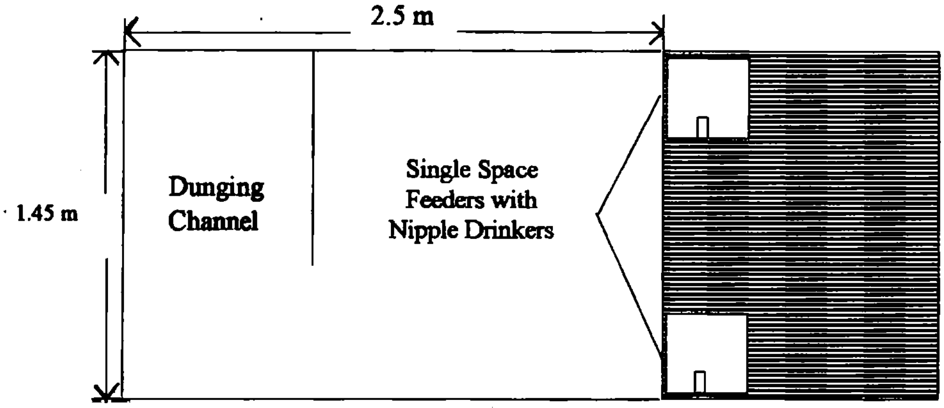
An eight-day training period, in which the pigs were allowed access to only one of the two feeds on alternate days, was used at the beginning of

TABLE 2.1. Composition (g/kg) and analysis of the basal feeds.

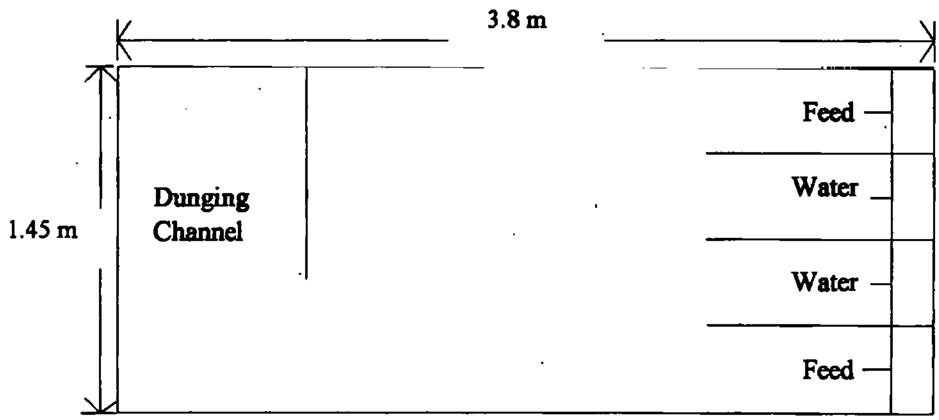
Feed	Low Protein	High Protein
Dietary protein content (g/kg feed)	98	225
Ingredient		
Ground maize	929.1	664.0
Wheat bran		25.0
Fish meal	32.1	121.6
Soya bean meal		164.4
Lysine	1.2	2.4
Methionine		2.6
Salt	2.5	
Limestone powder	3.8	
Dicalcium phosphate	11.3	
Vits/mins supplement	20.0	20.0
Analysis (calculated unless otherwise stated)		
Protein (determined - gN x 6.25/kg)	98.0	225.1
DE (MJ/kg)	14.3	14.6
Digestible Lysine (g/kg digestible protein)	50.4	71.5
Digestible Methionine (g/kg digestible protein)	25.1	32.4
Digestible Threonine (g/kg digestible protein)	34.4	38.0

FIGURE 2.1. Pen Layouts

3 Pigs per Pen



1 Pig per Pen



the experiment. The training period improves the ability of pigs to select a balanced diet (Kyriazakis, Emmans and Whittemore, 1988) and has been used successfully in experiments by Kyriazakis *et al* (1991) and Bradford and Gous (1991). The experiment lasted four weeks after the initial training period had elapsed.

1Statistical analysis of the data was performed by analysis of variance using the GENSTAT statistical package (Lawes Agricultural Trust, 1984). A randomised block split-plot design was used in which the number of pigs per pen were the main plots and the dietary treatments were the split plots. Orthogonal comparisons allow the sub-division of the treatment sum of squares to make comparisons between sub-sets of the data (Mead and Curnow, 1983).The two orthogonal comparisons that were performed were between the high plus low treatment versus the high plus medium low treatment, and the mean of the high plus low and high plus medium low treatments versus the medium high plus low treatment.

2.1.3. Results

(i) Selection of Dietary Protein Concentration

Feed intake did not differ between the three dietary choice treatments ($P > 0.05$). In the first half of the selection period both the high plus medium low ($P < 0.001$) and the medium high plus low ($P < 0.05$) protein treatments had growth rates more than 15% lower than the high plus low protein treatment. In the second half of selection the medium high plus low protein treatment had a growth rate more than 10% lower than the other two treatments ($P < 0.05$). Feed conversion efficiency (FCE) did not differ between the treatments except in the first half of selection where the high plus low protein treatment had an increased FCE. There was an unexplained difference between the initial weights of the three dietary treatments ($P < 0.05$). A covariance analysis was used to adjust the parameters of productive performance for differences in initial body weight. However, this did not decrease the residual sum of squares of any of the parameters. Treatment means of initial weight, daily feed intakes, average daily weight gains and FCE are shown unadjusted (Table 2.2).

TABLE 2.2. Effect of dietary choice, number of pigs per pen and food presentation on weight gain, feed intake and feed conversion efficiency.

		Average Weight Gain (kg/day)			Average Feed Intake (kg/day)			Feed Conversion Efficiency		
	Initial Weight	Training Period	Days 1-14 of Selection	Days 15-28 of Selection	Training Period	Days 1-14 of Selection	Days 15-28 of Selection	Training Period	Days 1-14 of Selection	Days 15-28 of Selection
Choice:										
High + Low	15.70	0.352	0.845	0.928	0.820	1.357	1.871	0.43	0.62	0.50
High + Medium Low	14.07	0.391	0.687	0.914	0.769	1.425	1.837	0.51	0.50	0.51
Medium High + Low	16.26	0.267	0.671	0.813	0.731	1.361	1.853	0.40	0.50	0.43
Orthogonal Comparisons:										
(H+L and H+ML) vs MH+L	*	NS	*	*	NS	NS	NS	NS	*	*
H+L vs H+ML	*	NS	***	NS	NS	NS	NS	NS	***	NS
Pigs per pen:	NS	NS	NS	**	*	NS	NS	NS	NS	NS
1	15.38	0.291	0.735	0.917	0.702	1.407	1.894	0.44	0.54	0.48
3	15.31	0.382	0.733	0.854	0.844	1.356	1.814	0.45	0.54	0.48
Food Form:	NS	NS	NS	NS	NS	NS	*	NS	*	NS
Pellets	15.42	0.325	0.746	0.896	0.768	1.331	1.723	0.45	0.57	0.51
Meal	15.27	0.348	0.723	0.874	0.778	1.432	1.985	0.44	0.51	0.45
Grand Mean	15.35	0.336	0.734	0.885	0.773	1.381	1.854	0.44	0.51	0.48
SEM:										
Diet (10 df)	0.429	0.0459	0.023	0.033	0.053	0.064	0.078	0.035	0.016	0.025
Pigs per pen (2 df)	1.998	0.1566	0.069	0.034	0.098	0.186	0.136	0.047	0.423	0.007
Food form (10 df)	0.350	0.0375	0.019	0.027	0.043	0.053	0.063	0.029	0.013	0.021

NS $P > 0.05$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Total daily protein consumption was lower for the medium high plus low protein treatment than for the other two treatments throughout the experiment. The high plus low protein treatment tended to have a higher daily protein consumption than the high plus medium low protein treatment (Table 2.3).

During the training period all three choice treatments ate a similar proportion of the higher protein feed offered, at a rate of about 60% of the total feed eaten (Table 2.4). During the selection period the high plus medium low protein treatment ate less of the higher protein feed than the other two treatments.

There was a difference between the concentrations of protein consumed in the different dietary choices; the diet selected by pigs on the medium high plus low protein choice had a lower protein concentration than the diets selected by the other two treatments (Table 2.5). The high plus low protein treatment consumed a lower protein concentration than the high plus medium low protein treatment in the training period, and a higher concentration of protein in the first half of the selection period.

The protein concentration consumed by individual pigs or pens of pigs

TABLE 2.3. Effect of dietary choice, number of pigs per pen and food presentation on the amount of protein consumed (kg/day).

	Crude Protein Consumed (kg/day)		
	Training Period	Days 1-14 of Selection	Days 14-28 of Selection
Choice:			
High + Low	0.157	0.305	0.400
High + Medium Low	0.134	0.272	0.361
Medium High + Low	0.110	0.239	0.322
Orthogonal Comparisons:			
(H+L and H+ML) vs MH+L	*	***	*
H+L vs H+ML	NS	***	NS
Pigs per pen:	*	NS	*
1	0.118	0.279	0.380
3	0.150	0.265	0.342
Food Form:	NS	**	**
Pellets	0.128	0.262	0.329
Meal	0.139	0.282	0.393
Grand Mean	0.134	0.272	0.361
SEM:			
Diet (10 df)	0.0104	0.0039	0.0152
Pigs per pen (2 df)	0.0232	0.0339	0.0229
Food form (10 df)	0.0085	0.0032	0.0124

NS P > 0.05, * P < 0.05, ** P < 0.01, *** P < 0.001

TABLE 2.4. Effect of dietary choice, number of pigs per pen and food presentation on the proportion of higher protein food consumed.

	Proportion of Higher Protein Food Consumed		
	Training Period	Days 1-14 of Selection	Days 14-28 of Selection
Choice:			
High + Low	0.615	0.993	0.992
High + Medium Low	0.546	0.739	0.834
Medium High + Low	0.650	0.965	0.982
Orthogonal Comparisons:			
(H+L and H+ML) vs MH+L	NS	NS	NS
H+L vs H+ML	NS	*	NS
Pigs per pen:	***	NS	NS
1	0.549	0.956	0.936
3	0.613	0.842	0.845
Food Form:	NS	NS	NS
Pellets	0.592	0.885	0.881
Meal	0.614	0.914	0.900
Grand Mean	0.603	0.899	0.891
SEM:			
Diet (10 df)	0.0166	0.0093	0.0823
Pigs per pen (2 df)	0.0392	0.0158	0.1542
Food form (10 df)	0.0135	0.0076	0.6720

NS P > 0.05, * P < 0.05, *** P < 0.001

TABLE 2.5. Effect of dietary choice, number of pigs per pen and food presentation on the protein concentration consumed (g/kg of feed).

	Protein Concentration Consumed (g/kg feed)		
	Training Period	Days 1-14 of Selection	Days 14-28 of Selection
Choice:			
High + Low	176.1	224.1	207.9
High + Medium Low	186.4	202.8	213.7
Medium High + Low	150.0	175.2	173.2
Orthogonal Comparisons:			
(H+L and H+ML) vs MH+L	***	***	**
H+L vs H+ML	*	*	NS
Pigs per pen:	**	NS	NS
1	170.2	205.6	203.8
3	171.4	195.8	192.7
Food Form:	NS	NS	NS
Pellets	169.7	199.4	196.5
Meal	171.9	202.0	200.0
Grand Mean	170.8	200.7	198.2
SEM:			
Diet (10 df)	2.51	5.44	7.96
Pigs per pen (2 df)	0.49	15.89	21.15
Food form (10 df)	2.05	4.45	6.50

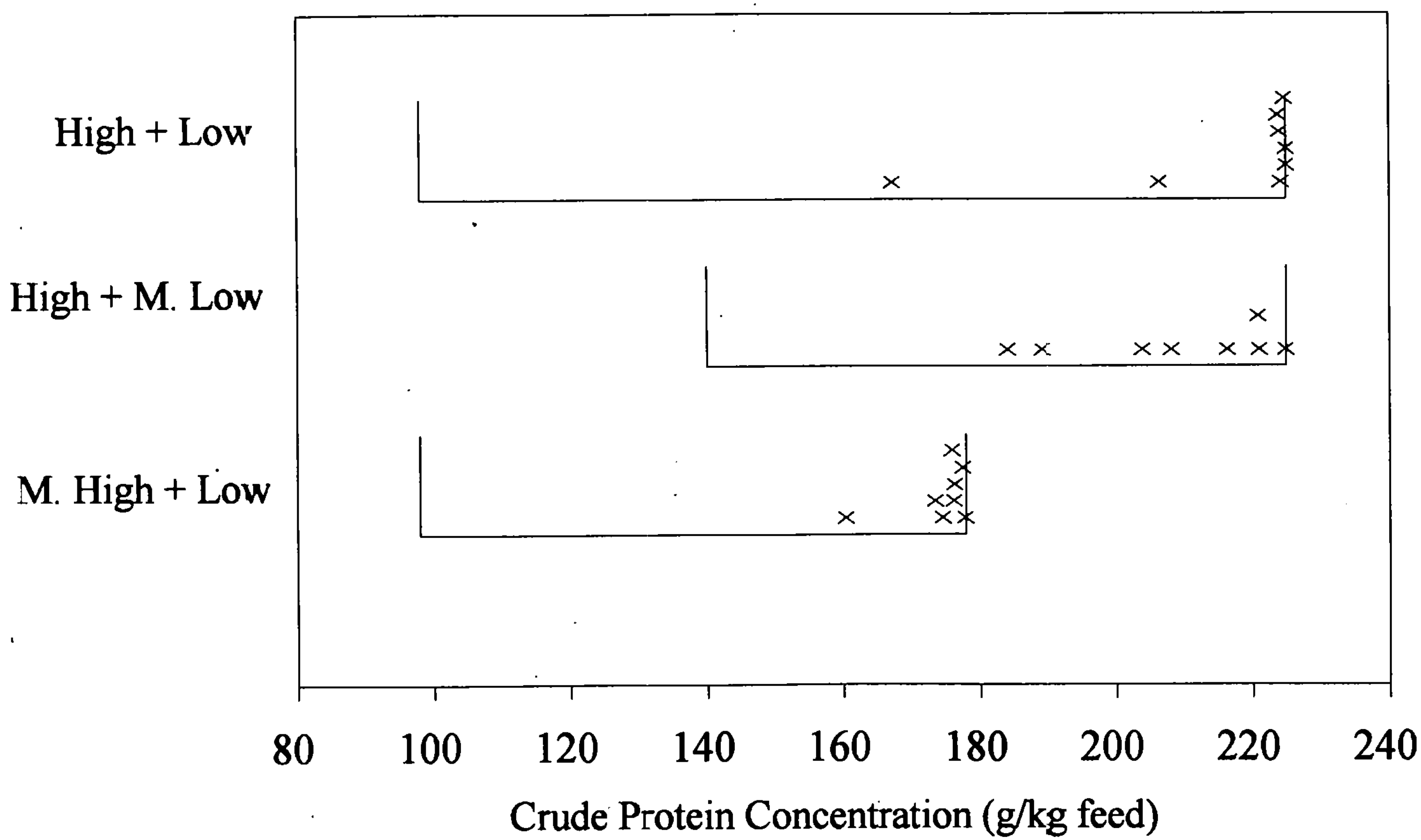
NS P > 0.05, * P < 0.05, ** P < 0.01, *** P < 0.001

(Figure 2.2) showed that most pigs were only eating one of the two feeds offered. This was especially true where the choice included the low protein feed, although even on the high plus medium low protein treatment six of the eight pigs ate mostly (> 85%) the high protein feed.

(ii) Social Effects

Initial weight was similar for both single and grouped pigs, as were weight gains for the first three weeks of the experiment (Table 2.2). However, during the last two weeks of the experiment the single pigs had higher weight gains ($P < 0.01$). Feed intakes were similar for both singly and group housed pigs, except during the training period when the single pigs ate less ($P < 0.05$). The single pigs also ate a smaller proportion of the higher protein feed during the training period ($P < 0.001$) and, consequently, had a lower total protein intake (Table 2.3, $P < 0.05$) and a lower protein concentration (Table 2.5, $P < 0.01$). In the second half of the selection period the single pigs had a higher total protein intake than the group housed pigs ($P < 0.05$).

FIGURE 2.2. Protein concentration selected by individual growing pigs on different dietary choices.



Vertical lines on graph represent the protein concentration of the feeds offered.

(iii) Feed Presentation

There were no differences in weight gains between the two feed presentations offered. Feed intake tended to be lower and FCE tended to be higher for pelleted feed than for meal, although this was only significant in the second half of the selection period (Table 2.2, $P < 0.05$). Total protein intake was higher for the pigs fed on meal than the pellet fed pigs during the selection period (Table 2.3, $P < 0.01$). The form of feed presentation had no effect on the proportion of the higher protein feed consumed or the concentration of protein consumed ($P > 0.05$).

2.1.4. Discussion

(i) Selection of Dietary Protein Concentration

Growing pigs appeared to be able to select feeds on the basis of their digestible protein concentration. However, in contrast to other studies (Kyriazakis *et al*, 1990, Bradford and Gous, 1991) few pigs selected a blend of feeds which provided an digestible protein concentration appropriate to their requirements, tending instead to eat mainly the higher protein feed.

The pigs on the choice between medium high protein and low protein grew more slowly than the pigs on the other two treatments. These pigs consumed less protein and a lower protein concentration than the other pigs, because the protein content of the medium high feed was only 178 g kg^{-1} of feed, which suggests that the medium high protein feed was below the protein requirements of these pigs. However, the pigs on the choice between the high and the low protein feeds all ate virtually all their diet from the high protein feed. This may suggest that 225 g protein kg^{-1} feed is also below growing pigs requirements. However. it is possible that the pigs selected the one feed nearest to their requirements, rather than selecting a mixture of feeds. Some of the pigs on the high plus medium low protein treatment did eat a mixture of the two feeds, but the majority of pigs ate mainly the high protein feed.

Bradford and Gous (1991) in a similar experiment used growing pigs between 30 and 85 kg, and in the first week of the experiment, when they were a similar size to the pigs used in this experiment, they selected 190-200 g protein kg^{-1} of feed, on the choices including the high protein feed. Those pigs on the medium high plus low protein diet consumed about 160 g protein kg^{-1} feed. However, the pigs were penned in groups of ten, so it is impossible to know what individual pigs selected. The pigs used in that experiment were relatively unimproved and this may explain the slightly lower protein concentrations selected. Comparative diet selection experiments have shown that Chinese pigs which have not been genetically improved select a lower protein diet than improved pigs, reflecting their lower potential for lean tissue growth (Kyriazakis and Leus, 1992). In another experiment, 12-30 kg pigs on four different dietary choices all selected between 202 and 208 g protein kg^{-1} feed (Kyriazakis *et al*, 1990).

The Agricultural Research Council (1981) recommended a protein concentration of 12 g MJ^{-1} digestible energy for 15-50 kg growing pigs, which is around 172 g protein kg^{-1} feed, about 24% less than the high protein feed in this experiment. In the US, the National Research Council (1988) suggested even lower concentrations than this, 150 g protein kg^{-1} feed for pigs weighing 20 to 50 kg.

(ii) Social Effects

During the training period there were some differences between the singly and group housed pigs. The single pigs ate less feed and a smaller proportion of the higher protein feed, which resulted in lower total protein consumption and concentration of protein in the diet. One possible explanation is that single pigs did not learn to eat as quickly as groups of pigs, since there was no social stimulation. The grouped pigs may have eaten a larger proportion of the higher protein feed because learning the properties of the feeds was facilitated by observing others in the group. Thus, the grouped pigs were selecting a diet higher in protein than the single pigs before the selection period began. Towards the end of the experiment the single pigs were growing more than the group housed pigs. This may have been due to increased competition for feeder space in the grouped pigs as their feed intake increased. The single pigs would have enough time to eat as much as they required, while the group fed pigs may have had a constraint on feeding time.

(iii) Feed Presentation

The pigs fed meal tended to consume more feed than the pigs fed pellets. Since growth rates were not affected by this increased intake, and FCE fell by up to 17% in the meal fed pigs, it is possible that the extra meal apparently consumed was in fact wasted. The total amount of protein consumed was greater when meal was fed, but the proportion of higher protein feed consumed and the concentration of protein consumed were similar for both presentations. This suggests that, despite the increased wastage of meal, feed presentation had no effect on pigs ability to select protein concentration.

2.1.5. Conclusions

(i) Selection of Dietary Protein Concentration

Growing pigs could detect the difference between two feeds differing only in protein concentration; however, in this experiment most pigs ate mainly only one of the two feeds offered. In all treatments the preferred feed was the higher protein feed. This may have been due to the fact that all the feeds were below or close to their requirements or that the pigs selected the single feed closest to their requirements.

(ii) Social Effects

Housing pigs singly appears to slightly slow down the learning phase in the selection of an appropriate diet, but does not have any effect on the resultant diet selected.

(iii) Feed Presentation

In both the single space feeders and the troughs used in this experiment, it would appear that there is more efficient utilisation of feed presented as pellets than as meal, but with both the pigs were capable of selecting a diet that met their protein requirements.

2.2. Selection of dietary lysine concentration by growing pigs.

2.2.1. Introduction

There is some evidence that growing pigs can select to some degree for imbalances of amino acids (Devilat, Pond and Miller, 1970) and can detect excess concentrations of some amino acids (Edmonds, Gonyou and Baker, 1987). This evidence suggests that growing pigs can detect different concentrations of amino acids in feeds, and consequently, should be able to select a diet to meet their requirements from two feeds differing only in their concentration of one amino acid.

In 1981 the Agricultural Research Council (ARC) published its *Nutrient Requirements of Pigs*, in which it was proposed that the amino acid requirements of pigs could be described as an ideal balance of amino acids. Concentrations of individual amino acids are expressed relative to the protein content of the feed.

The concentration of lysine in the ideal protein for pigs was estimated to be around 70 g kg^{-1} protein (ARC, 1981), although there have been estimates as low as 59 g kg^{-1} protein (Fuller, McWilliam, Wang and Giles, 1989). In the USA, the National Research Council (NRC, 1988) recommends an even lower concentration of 0.75% lysine in a diet with 15% crude protein for 20-50 kg pigs, which is 50 g kg^{-1} protein.

The objective of this experiment was to discover if growing pigs offered two feeds differing only in their lysine contents could select an optimal concentration of lysine for growth.

2.2.2. Methods and Materials

(i) Choice-Fed Pigs

A diet selection experiment was conducted at the experimental pig house, Harper Adams Agricultural College, Shropshire. Forty male pigs, approximately seven weeks old and with an initial mean weight of 13.1 kg, were allocated to one of four dietary choice treatments, each treatment consisting of two feeds of differing lysine concentration.

The four dietary choices provided were:

1. High Lysine	+	Low Lysine
2. High Lysine	+	Medium Low Lysine
3. Medium High Lysine	+	Low Lysine
4. Medium High Lysine	+	Medium Low Lysine

A basal lysine-deficient feed was formulated, with a digestible protein content of 172 g kg^{-1} feed. This feed was supplemented with synthetic lysine to form four feeds with digestible lysine contents of 25 g (low lysine), 50 g (medium low lysine), 109 g (medium high lysine) and 141 g (high lysine) kg^{-1} digestible protein. The composition of the low and high lysine feeds is shown in Table 2.6.

All the pens were in the same house and were equipped with two single space feeders and a separate nipple drinker (Figure 2.3). The pigs were allowed *ad libitum* access to both food and water.

Treatments were allocated randomly to the pens in each block. Each feed was allocated at random to one of the two feeders in each pen. All the feeds were presented as pellets. All the pigs were weighed at the start of the experiment and once a week thereafter. Feed consumed was recorded for a three day and a four day period each week throughout the experiment.

Twenty four pens were available at any one time, so the experiment was carried out over two time replicates with twenty four and sixteen pigs.

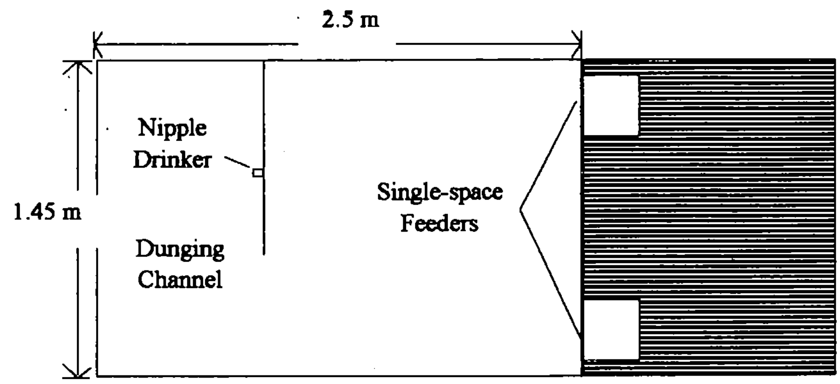
The first twenty four male pigs, with an initial mean weight of 11.3 kg, were given an eight day training period at the beginning of the experiment, in which they were allowed access to each food on alternate days. This length of training period has been shown to significantly

TABLE 2.6. Composition (g/kg feed) and analysis of the basal feeds.

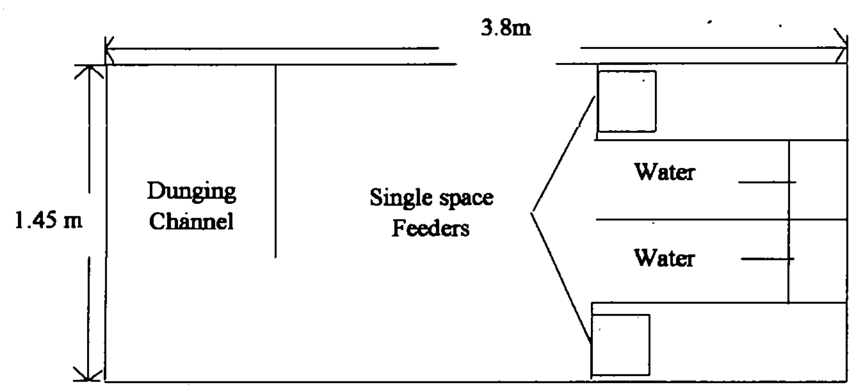
Feed	Low Lysine	High Lysine
Digestible Lysine Concentration (g/kg digestible protein)	25	141
Ingredient		
Wheat	596.5	596.5
Vegetable Oil	30.0	30.0
Sunflower Meal	150.0	150.0
Maize Gluten Meal	145.0	145.0
Maize Starch	31.0	0.5
Lysine		30.5
Methionine	1.0	1.0
Threonine	3.0	3.0
Salt	3.5	3.5
Dicalcium phosphate	20.0	20.0
Vits/mins supplement	20.0	20.0
Analysis (calculated unless otherwise stated)		
Crude Protein (determined - g N x 6.25/kg)	220.1	242.5
Digestible Protein (g/kg feed)	172.1	200.9
DE (MJ/kg feed)	14.43	14.43
Digestible Lysine (g/kg digestible protein)	24.7	141.8
Digestible Methionine (g/kg digestible protein)	25.1	21.5
Digestible Threonine (g/kg digestible protein)	46.4	39.7

FIGURE 2.3. Pen layouts.

Choice-fed Pigs



Single-fed Pigs



improve the ability of pigs to select a diet that is balanced for protein (Kyriazakis *et al*, 1988). After the initial training period, the experiment lasted for two weeks.

The second time replicate of sixteen male pigs, with a mean weight of 15.8 kg, were housed in 16 pens in the experimental house. They were given a fourteen day training period at the beginning of the experiment, in which they were allowed access to each feed on alternate days. After the initial training period, the experiment lasted three weeks.

(ii) Single-Fed Pigs

An experiment was conducted at the experimental pig house, Harper Adams Agricultural College, Shropshire with twenty-four male growing pigs, approximately nine weeks old and with an initial mean weight of 19.6 kg. Each pig was allocated at random to one of six dietary treatments, each consisting of a single feed. The four feeds described above were used, with two additional intermediate feeds to allow better investigation of the growth response to added synthetic lysine in the base feed.

1. Low lysine	25 g kg^{-1} digestible protein
2. Medium Low lysine	50 g kg^{-1} digestible protein
3. Intermediate Low lysine	62 g kg^{-1} digestible protein
4. Intermediate High Lysine	89 g kg^{-1} digestible protein
5. Medium High lysine	109 g kg^{-1} digestible protein
6. High Lysine	141 g kg^{-1} digestible protein

Pigs were given *ad libitum* access to the feed in two single space feeders in each pen. Water was available *ad libitum* from two troughs situated at the front of the pen (Figure 2.3).

All the pens in the experimental house were used. Treatments were allocated randomly to the pens in each block. All the pigs were weighed on three consecutive days every week and a mean value calculated. Feed consumed was recorded for a three day and a four day period each week throughout the experiment. There was no training period so to allow a better comparison of data, these pigs were two weeks older than the choice-fed pigs at the start of the experiment. The experiment lasted fourteen days.

Statistical analysis of all the experimental data was performed according to a randomised block analysis of variance of the measured and calculated variables, using the GENSTAT statistical package (Lawes Agricultural Trust, 1984).

2.2.3. Results

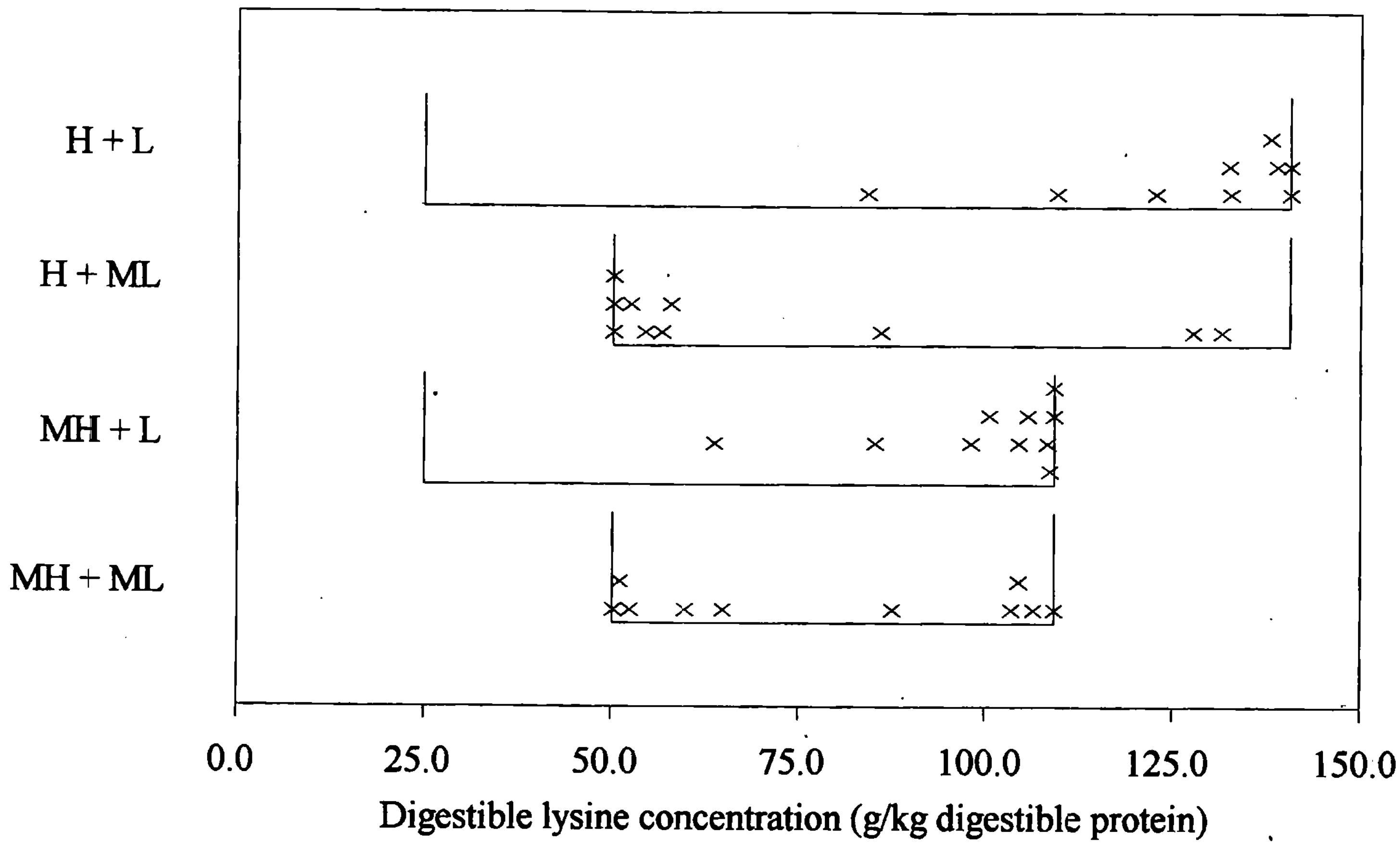
(i) Choice-Fed Pigs

Pigs clearly discriminated between the two feeds they were offered, tending to eat one or the other (Figure 2.4). When the choice included the low lysine food, they all rejected it in favour of the high lysine feed or the medium high lysine feed. However, when given a choice between the medium low lysine feed and the high Lysine feed, most pigs preferred the lower lysine feed. They were more equally divided in their choice between the medium high and medium low lysine feeds, with some pigs eating mostly medium high and some pigs eating mostly medium low.

There were no differences between the dietary choices in initial weight, weight gain, feed intake, feed conversion efficiency or the total amount of digestible lysine consumed per day (Tables 2.7 and 2.8).

Throughout the selection period the digestible lysine concentration selected varied between the treatments, although these differences increased over time. The pigs given a choice that included the low lysine feed selected higher concentrations of digestible lysine than those on the

FIGURE 2.4. Lysine concentration selected by individual growing pigs on different dietary choices.



Vertical lines on the graph represent the lysine concentration of the feeds offered.

TABLE 2.7. Effect of dietary choice treatment on weight gain, feed intake and feed conversion efficiency of growing pigs in the first two weeks of selection.

	Initial Weight (kg)	Weight Gain (kg/day)	Food Intake (kg/day)	Feed Conversion Efficiency
Choice:	NS	NS	NS	NS
High + Low	12.85	0.603	1.144	0.512
High + Medium Low	13.09	0.714	1.144	0.491
Medium High + Low	13.16	0.607	1.127	0.535
Medium High + Medium Low	13.27	0.665	1.295	0.495
Mean	13.09	0.647	1.253	0.508
SEM (34 df)	0.816	0.0691	0.0949	0.0322

NS P > 0.05

TABLE 2.8. Effect of dietary choice treatment on the amount of digestible lysine consumed by growing pigs.

	Digestible lysine consumed (g/day)			
	Days 1-4 of selection	Days 5-7 of selection	Days 8-11 of selection	Days 12-14 of selection
Choice:	NS	NS	NS	NS
High + Low	26.1	24.7	28.6	30.1
High + Medium Low	18.3	16.5	19 6	24.6
Medium High + Low	17.6	17.5	25.9	21.4
Medium High + Medium Low	17.7	16.3	18.8	21.9
Mean	19.9	18.8	23.2	24.5
SEM (34 df)	2.91	2.9	3.15	3.67

NS $P > 0.05$

other two treatments (Table 2.9). There was also a difference in the proportion of the higher lysine feed selected throughout the experiment, and this too was more pronounced in the second half of the selection period (Table 2.10).

Length of Training Period

The digestible lysine concentration selected in the treatments which included the low lysine feed increased over time when the pigs had an eight day training period (Figure 2.5, $P < 0.01$), whereas it did not change over time when the pigs had a fourteen day training period (Figure 2.6, $P > 0.05$). This meant that the data for the pigs on the eight day training period was more variable than that of the pigs on the fourteen day training period. The results for the different training period lengths can be found in Appendix A.

(ii) Single-fed Pigs

There was a non-linear relationship between weight gain and lysine concentration in the single-fed pigs. Weight gain increased with increasing lysine concentration until 62.5 g lysine kg^{-1} digestible protein, after this

TABLE 2.9. Effect of dietary choice treatment on the digestible lysine concentration consumed by growing pigs.

	Digestible lysine conc. (g/kg digestible protein)			
	Days 1-4 of selection	Days 5-7 of selection	Days 8-11 of selection	Days 12-14 of selection
Choice:				
High + Low	112.3	110.4	129.0	124.3
High + Medium Low	72.1	70.9	68.8	75.3
Medium High + Low	89.4	91.4	99.4	99.9
Medium High + Medium Low	77.9	76.9	78.4	79.5
Mean	87.9	87.4	93.9	94.7
SEM (34 df)	7.32	9.08	7.79	7.94

TABLE 2.10. Effect of dietary choice treatment on the proportion of higher lysine feed consumed by growing pigs.

	Proportion of higher lysine feed selected			
	Days 1-4 of selection	Days 5-7 of selection	Days 8-11 of selection	Days 12-14 of selection
Choice:				
High + Low	0.734	0.722	0.889	0.844
High + Medium Low	0.227	0.220	0.199	0.266
Medium High + Low	0.754	0.778	0.876	0.883
Medium High + Medium Low	0.457	0.445	0.472	0.488
Mean	0.543	0.541	0.609	0.620
SEM (34 df)	0.0876	0.1073	0.1026	0.1007

FIGURE 2.5. The change in lysine concentration selected by growing pigs with an eight-day training period.

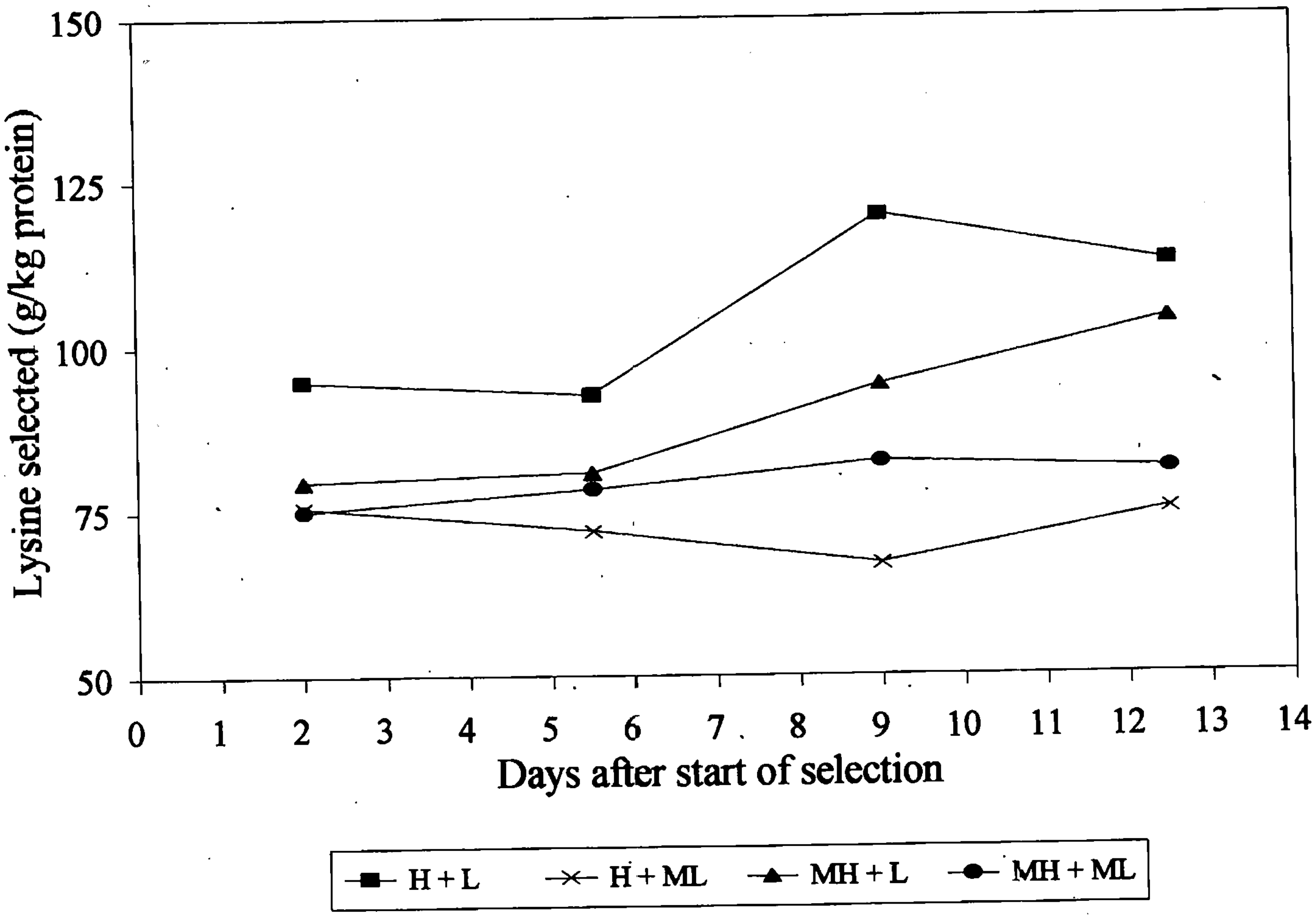
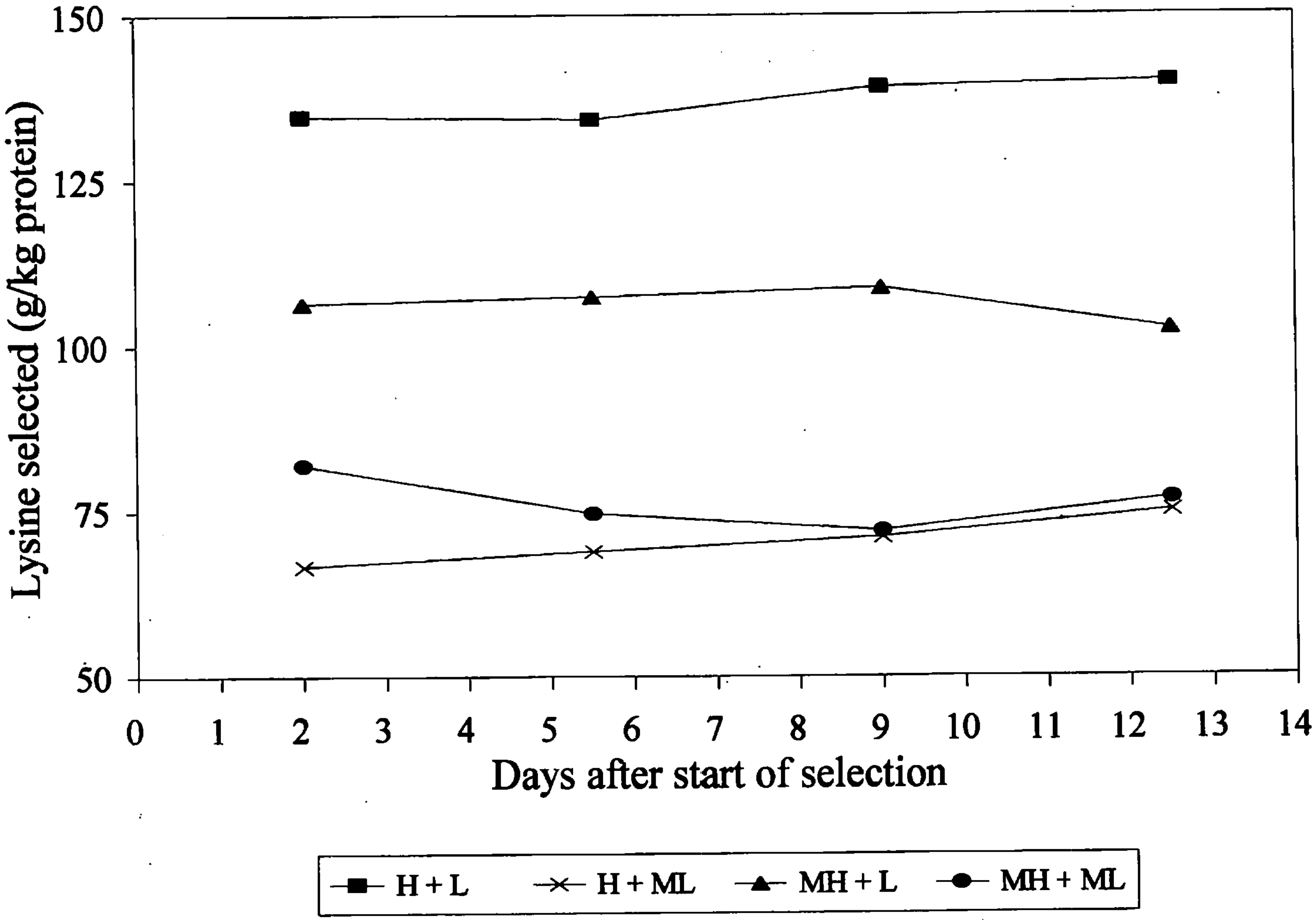


FIGURE 2.6. The change in lysine concentration selected by growing pigs with a fourteen-day training period.



concentration weight gain fell to a constant level, at about 50% of the maximum (Figure 2.7). There was no difference between the treatments in feed intake, which led to differences in FCE between treatments ($P > 0.01$, Table 2.11). The amount of lysine consumed differed between treatments ($P > 0.001$, Table 2.11), although the pigs fed the intermediate high and medium high lysine feeds had a tendency to consume less feed, which meant that these pigs did not consume much more lysine than the pigs fed the intermediate low and medium low lysine feeds.

FIGURE 2.7. Mean weight gain of single-fed pigs fed differing digestible lysine concentrations.

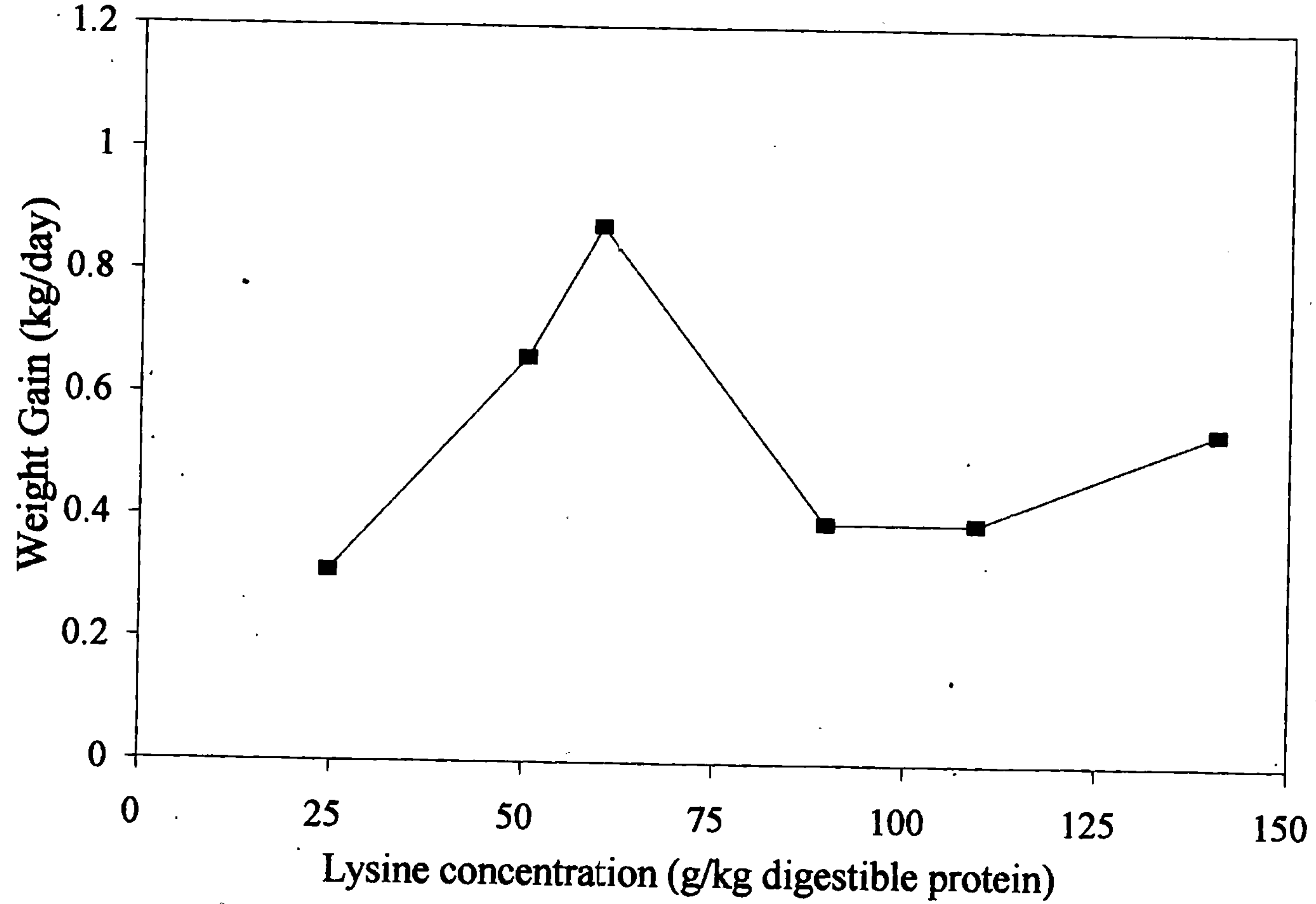


TABLE 2.11. Effect of dietary lysine concentration on weight gain, feed intake, feed conversion efficiency and amount lysine consumed in single-fed pigs.

	Initial Weight (kg)	Weight Gain (kg/day)	Feed Intake (kg/day)	Feed Conversion Efficiency	Lysine Consumed (g/day)
Digestible Lysine Concentration (g/kg digestible protein)	NS	*	NS	**	***
25	18.30	0.311	1.101	0.280	4.7
50	21.25	0.661	1.413	0.464	12.6
62	22.15	0.875	1.533	0.571	16.6
89	18.58	0.393	0.868	0.431	14.5
109	17.25	0.393	0.859	0.437	18.0
141	20.40	0.545	1.214	0.432	34.3
Mean	19.65	0.529	1.165	0.436	16.8
SEM (15 df)	1.549	0.0999	0.1665	0.0418	3.01

NS $P > 0.05$, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

2.2.4. Discussion

The pigs in this experiment could distinguish between feeds on the basis of their digestible lysine concentration. However, in contrast to other diet selection studies (Kyriazakis *et al*, 1990) few pigs selected a blend of feeds which provided an appropriate digestible lysine concentration, choosing instead the single feed which was probably most suitable for their needs. The feed selected was not necessarily the one closest to published requirements.

The effects that differing lysine concentrations have on the pig may be less easy to detect than the effects of differing protein concentrations, so that a longer training period may be required to allow the pig to distinguish between the feeds. Lysine is a relatively non-toxic amino acid and excess is oxidised in a different pathway from that of other amino acids, thus there is no competition with other amino acids. Pigs offered a choice of diets with an additional 4% of synthetic amino acids preferred an excess of lysine to an excess of methionine, tryptophan or arginine (Edmonds *et al*, 1987). In that study growth was greater in pigs given the excess lysine diet compared to diets with excess methionine, tryptophan or arginine. Thus the metabolic consequences of consuming too much lysine may not be very great. However, the reduction in growth and the metabolic consequences of consuming excess amounts of all the other amino acids, when too low a lysine concentration is consumed might be expected to be larger, as was seen in the single-fed pigs. This would explain the almost total avoidance of the low lysine feed. Since the pigs did not avoid the medium low lysine feed, but actively chose it over the high lysine feed, it would seem possible that it is nearer to the ideal lysine concentration than originally thought.

In a similar experiment, Henry (1987) found that some selection for lysine did occur, but that it was not constant between the different dietary choices offered. However, unlike this experiment it appeared that some blending of the feeds did occur. This may have been similar to the apparent blending that occurred in the first week of selection of the pigs with an eight day training period, when the pigs could not accurately distinguish between the feeds. Henry (1987) gave no training period to allow the pigs to assess the different properties of the feeds offered. The highest concentrations of lysine offered were 80 g kg^{-1} protein (cf. ARC recommendations of 70 g kg^{-1} protein) and many of the dietary choices consisted of two feeds with lower lysine concentrations than this, which would prevent the pigs from selecting an optimal concentration. In

Henry's experiment feeder position was changed every week, which prevented the pigs from using this as a cue, and this resulted in the lysine concentration selected changing every week.

2.2.5. Conclusions

(i) Growing pigs could detect a difference in lysine concentration between two feeds and use this ability to select a diet. However, most of the pigs did not select a balance of the two feeds appropriate to their needs, choosing instead to eat mainly the single feed most suitable for their needs. This is in contrast to published conclusions for the selection of protein concentration.

(ii) A training period of eight days did not appear to be long enough for growing pigs to learn the properties of feeds that varied in lysine concentration. When the pigs were given too short a training period they continued to make changes in their diet after the training period ended. Increasing the training period to fourteen days allowed the pigs to select their desired diet immediately selection began.

2.3. Selection of dietary threonine concentration by growing pigs.

2.3.1. Introduction

The previous experiment showed that growing pigs can discriminate between two feeds with different lysine concentrations, but they did not eat a balance of the two feeds appropriate to their needs. Instead the pigs chose to eat mainly the single feed more suitable for their needs.

The concentration of threonine in the ideal protein for pigs has been estimated to be around 42 g kg^{-1} protein (ARC, 1981). Other estimates since then have generally been higher than this, with some as high as 47 g kg^{-1} protein (Moughan and Smith, 1984; Wang and Fuller, 1989). One recent estimate suggests a lower value of 35 g kg^{-1} protein (Chung and Baker, 1992), but this was for pigs of 10 kg. The NRC (1988) recommended 0.48% threonine in a diet with 15% crude protein for 20-50 kg pigs, which is 32 g kg^{-1} protein.

The objective of this trial was to discover if growing pigs offered two feeds differing only in their threonine contents could select an optimal concentration of threonine for growth.

2.3.2. Methods and Materials

(i) Choice-Fed Pigs

A diet selection experiment was conducted at the experimental pig house, Harper Adams Agricultural College, Shropshire. Forty-eight male growing pigs, approximately seven weeks old and with an initial mean weight of 11.3 kg, were allocated to one of four dietary choice treatments, each treatment consisting of two feeds of differing threonine concentration.

The four dietary choices provided were:

1. High threonine + Low threonine
2. High threonine + Medium Low threonine
3. Medium High threonine + Low threonine
4. Medium High threonine + Medium Low threonine

A basal threonine-deficient feed was formulated, with a digestible protein content of 172 g kg^{-1} feed and a digestible threonine concentration of 25 g kg^{-1} digestible protein. This feed was supplemented with synthetic threonine to form four feeds with threonine concentrations of 29 g (low threonine), 35 g (medium low threonine), 55 g (medium high threonine) and 68 g (high threonine) kg^{-1} digestible protein. The composition of the low threonine feed is shown in Table 2.12.

All the pens were in the same house, and were equipped with two single space feeders and a separate nipple drinker (Figure 2.3, page 61). The pigs were allowed *ad libitum* access to both food and water.

Treatments were allocated randomly to the pens in each block. Each feed was allocated at random to one of the two feeders in each pen. All the feeds were presented as pellets. All the pigs were weighed on three consecutive days in each week of the experiment and a mean weight for each week was calculated. Feed consumed was recorded for a three day and a four day period each week throughout the experiment.

Twenty four pens were available at any one time, so the experiment was carried out over two time replicates.

A fourteen day training period was given at the beginning of the experiment, in which the pigs were allowed access to each of the feeds

TABLE 2.12. Composition (g/kg feed) and analysis of the basal feed.

Feed	Low Threonine
Digestible Threonine Concentration (g/kg digestible protein)	29
Ingredient	
Wheat	596.5
Vegetable Oil	30.0
Sunflower Meal	150.0
Maize Gluten Meal	145.0
Maize Starch	23.0
Lysine	11.0
Methionine	1.0
Salt	3.5
Dicalcium phosphate	20.0
Vits/mins supplement	20.0
Analysis (calculated unless otherwise stated)	
Total Crude Protein (determined gN x 6.25/kg feed)	224.9
Digestible Protein (g/kg feed)	179.6
DE (MJ/kg feed)	14.44
Digestible Lysine (g/kg digestible protein)	71.9
Digestible Methionine (g/kg digestible protein)	24.0
Digestible Threonine (g/kg digestible protein)	29.1

for alternate twenty four hour periods. In a previous experiment looking at selection for feeds differing in lysine content, a fourteen day training period was found to be more effective than an eight day training period used in protein experiments (Kyriazakis *et al*, 1990).

(ii) Single-Fed Pigs

An experiment was conducted at the experimental pig house, Harper Adams Agricultural College, Shropshire with twenty-four male growing pigs, approximately nine weeks old and with an initial mean weight of 19.9 kg. Each pig was allocated at random to one of six dietary treatments, each consisting of a single feed. The four feeds described above were used, with two additional intermediate feeds to allow better investigation of the growth response to added synthetic threonine in the base feed.

1. Low threonine	29 g kg^{-1} digestible protein
2. Medium Low threonine	35 g kg^{-1} digestible protein
3. Intermediate Low threonine	42 g kg^{-1} digestible protein
4. Intermediate High threonine	48 g kg^{-1} digestible protein
5. Medium High threonine	55 g kg^{-1} digestible protein

6. High threonine 68 g kg^{-1} digestible protein

Pigs were given *ad libitum* access to the feed in one single space feeder in each pen. Water was available *ad libitum* from a separate nipple drinker.

All the pens in the experimental house were used. Treatments were allocated randomly to the pens in each block. All the pigs were weighed three consecutive days every week and a mean value calculated. Feed consumed was recorded for a three day and a four day period each week throughout the experiment. There was no training period so to allow a comparison of data, these pigs were two weeks older than the choice-fed pigs at the start of the experiment. The experiment lasted fourteen days.

Statistical analysis of both experiments data was performed by analysis of variance of the measured and calculated variables, using the GENSTAT statistical package (Lawes Agricultural Trust, 1984).

2.3.3. Results

(i) Choice-Fed Pigs

Pigs clearly discriminated between the two feeds they were offered, tending to eat one or the other (Figure 2.8). In all the treatments the majority of pigs ate mainly (> 85%) from the lower threonine feed offered.

There were no differences between the treatments in initial weight, weight gain or feed intake. There was, however, a difference in feed conversion efficiency (FCE), with the treatments including medium low threonine tending to have a higher FCE ($P < 0.05$, Table 2.13). There was no difference in the total amount of digestible threonine consumed per day (Table 2.14). The mean threonine concentrations selected by the pigs on different treatments tended to be similar, although the mean concentration selected by the pigs on the choice between medium high plus low threonine feeds was consistently less than that of the other treatments (Table 2.15). The proportion of higher threonine feed selected was less than 0.5 for all treatments throughout the experiment (Table 2.16).

FIGURE 2.8. Threonine concentration selected by individual growing pigs on different dietary choices.

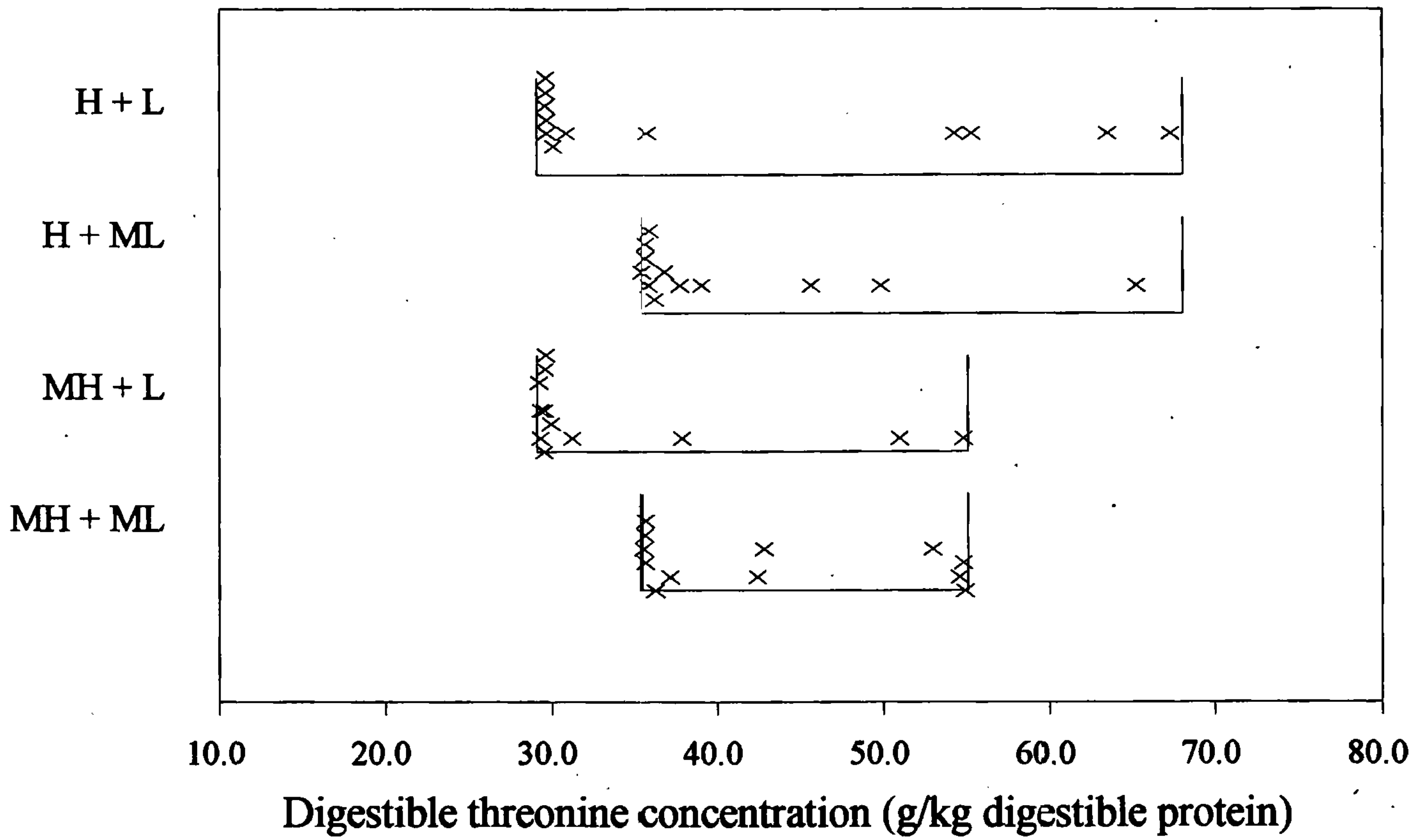


TABLE 2.13. Effect of dietary choice on weight gain, feed intake and feed conversion efficiency.

	Initial Weight (kg)	Weight Gain (kg/day)	Feed Intake (kg/day)	Feed Conversion Efficiency
Choice:	NS	NS	NS	*
High + Low	13.0	0.612	1.132	0.532
High + Medium Low	11.7	0.602	1.098	0.546
Medium High + Low	12.2	0.611	1.177	0.521
Medium High + Medium Low	12.5	0.718	1.173	0.613
Mean	12.3	0.636	1.145	0.553
SEM (33 df)	0.69	0.0415	0.0552	0.0242

NS $P > 0.05$, * $P < 0.05$

TABLE 2.14: Effect of dietary choice on the amount of threonine consumed.

	Digestible threonine consumed (g/day)			
	Days 1-3 of selection	Days 4-7 of selection	Days 8-10 of selection	Days 11-14 of selection
Choice:	*	NS	NS	NS
High + Low	7.4	8.4	9.1	8.5
High + Medium Low	7.0	8.1	8.0	8.8
Medium High + Low	5.7	6.5	7.8	9.6
Medium High + Medium Low	8.8	8.5	9.7	10.4
Mean	7.2	7.9	8.7	9.3
SEM (33 df)	0.74	0.92	0.96	1.13

NS $P > 0.05$, * $P < 0.05$

TABLE 2.15. Effect of dietary choice on threonine concentration selected.

	Digestible threonine concentration selected (g/kg DP)			
	Days 1-3 of selection	Days 4-7 of selection	Days 8-10 of selection	Days 11-14 of selection
Choice:				
High + Low	42.1	41.4	41.0	39.0
High + Medium Low	42.8	41.0	39.0	40.6
Medium High + Low	33.0	33.7	33.6	35.4
Medium High + Medium Low	44.8	44.6	42.5	41.9
Mean	40.9	40.2	39.0	39.2
SEM (33 df)	3.00	3.72	3.70	4.02

TABLE 2.16. Effect of dietary choice on proportion of higher threonine feed selected.

	Proportion of higher threonine feed selected			
	Days 1-3 of selection	Days 4-7 of selection	Days 8-10 of selection	Days 11-14 of selection
Choice:				
High + Low	0.349	0.306	0.303	0.255
High + Medium Low	0.222	0.315	0.108	0.158
Medium High + Low	0.152	0.169	0.176	0.243
Medium High + Medium Low	0.476	0.179	0.360	0.330
Mean	0.300	0.464	0.237	0.246
SEM (33 df)	0.0980	0.1215	0.1226	0.1329

(ii) Single-Fed Pigs

There was no relationship between weight gain and threonine concentration in the single-fed pigs (P > 0.05, Figure 2.9). The maximum weight gain was achieved on the low threonine feed. There were no differences between treatments in initial weight, weight gain, feed intake or FCE (Table 2.17). There was a difference between treatments of the amount of threonine consumed (P < 0.05, Table 2.17), but this difference is less than might be expected due to the tendency for the pigs on the threonine-deficient feeds to consume more feed than those on feeds with excess threonine.

FIGURE 2.9. Mean weight gain of single-fed pigs fed differing digestible threonine concentrations.

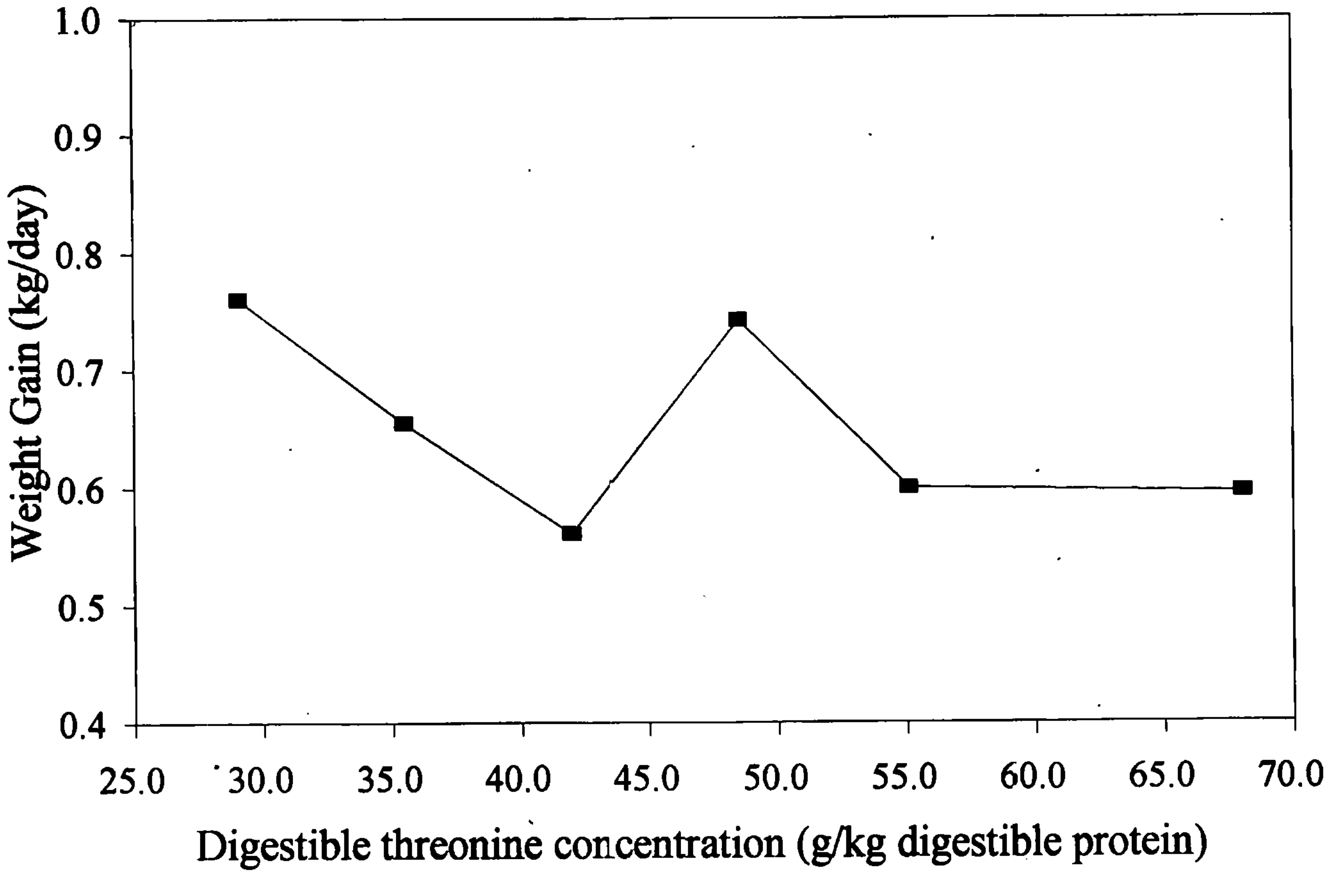


TABLE 2.17. Effect of dietary threonine concentration on weight gain, feed intake, feed conversion efficiency and amount threonine consumed.

	Initial Weight (kg)	Weight Gain (kg/day)	Feed Intake (kg/day)	Feed Conversion Efficiency	Threonine Consumed (g/day)
Digestible Threonine Concentration: (g/kg digestible protein)	NS	NS	NS	NS	*
29	20.75	0.761	1.522	0.504	7.96
35	21.25	0.655	1.248	0.526	8.01
42	20.83	0.561	1.245	0.445	9.53
48	18.92	0.743	1.314	0.565	11.69
55	19.42	0.600	1.069	0.562	10.89
68	18.48	0.596	1.149	0.521	14.65
Mean	19.94	0.653	1.258	0.520	10.45
SEM (15 df)	1.774	0.0726	0.1309	0.0293	1.149

NS $P > 0.05$, * $P < 0.05$

2.3.4. Discussion

There was no growth response to added synthetic threonine in the basal feed in the single-fed pigs. This suggests that either the basal feed was not deficient in threonine, or that the pigs were unable to utilise the synthetic threonine. It is possible that the single-fed pigs on the threonine-deficient feeds made up the deficiency by eating more, which they tended to do, although there was no significant difference in feed intake between treatments.

If the added threonine had no effect at all on the pigs, the choice-fed pigs would be expected to eat at random from the feeds, either eating a random amount from each feed or eating one feed at random. Since all the choice-fed pigs ate mainly from the lower threonine feeds, it seems likely that the synthetic threonine was disliked by the pigs, but whether this was due to excess threonine or some other factor, such as taste, is unclear.

2.3.5. Conclusion

Growing pigs appeared to detect differing threonine concentrations in a feed and used this ability to select a diet. All the pigs ate mainly the lower threonine feeds, suggesting that the basal feed was not limiting in threonine.

2.4. Selection of dietary lysine and threonine concentration by growing pigs

2.4.1. Introduction

Previous experiments carried out on diet selection of lysine and threonine alone showed that pigs could discriminate between feeds that differed only in their lysine or threonine contents. However these pigs did not select a balance of feeds appropriate for their needs. By presenting the pigs with feeds varying inversely in lysine and threonine contents, they might be forced to select a balance of the feeds to prevent excess or deficient amino acid intake.

The objective of this experiment was to discover if growing pigs offered two feeds differing only in their lysine and threonine contents could select optimal concentrations of lysine and threonine for growth.

2.4.2. Methods and Materials

A diet selection experiment was conducted at the experimental pig house, Harper Adams Agricultural College, Shropshire. Forty male growing pigs, approximately seven weeks old and with a mean weight of 14.8 kg, were allocated to one of four dietary choice treatments, each treatment consisting of two feeds with differing lysine and threonine concentrations.

The four dietary choices provided were:

1. High lysine-Low threonine + Low lysine-High threonine
2. High lysine-Low threonine + Medium Low lysine-High threonine
3. High lysine-High threonine + Low lysine-Low threonine
4. High lysine-High threonine + Medium Low lysine-Low threonine

A basal lysine- and threonine-deficient feed was formulated, with a digestible protein (DP) content of 168.5 g kg feed^{-1}. A further five feeds were formed by adding varying amounts of maize starch and synthetic lysine and threonine to the basal feed. The composition of the basal feed is shown in Table 2.18. The feeds were:

TABLE 2.18. Composition (g/kg feed) of the basal low lysine low threonine feed.

Feed	LLLT
Digestible lysine concentration (g/kg digestible protein)	25
Digestible threonine concentration (g/kg digestible protein)	31

Ingredient	Amount
Wheat	589.5
Vegetable Oil	30.0
Sunflower Meal	150.0
Maize Gluten Meal	145.0
Maize Starch	41.0
Methionine	1.0
Salt	3.5
Dicalcium Phosphate	20.0
Vits/Mins supplement	20.0

Analysis (calculated unless otherwise stated)	
Crude Protein (determined - g N x 6.25/kg)	200.5
Digestible Protein (g/kg feed)	168.5
DE (MJ/kg feed)	14.49
Digestible Lysine (g/kg digestible protein)	25.1
Digestible Threonine (g/kg digestible protein)	30.9
Digestible Methionine (g/kg digestible protein)	25.6

1. Low Lysine-Low Threonine (25 g lys + 29 g thr kg^{-1} DP)

2. Low Lysine-High Threonine (25g lys + 68 g thr kg^{-1} DP)

3. Medium Low Lysine-Low Threonine (50 g lys + 30 g thr kg^{-1} DP)

4. Medium Low Lysine-High Threonine (50 g lys + 68 g thr kg^{-1} DP)

5. High Lysine-Low Threonine (139 g lysine + 31 g thr kg^{-1} DP)

6. High Lysine-High Threonine (139 g lysine + 68 g thr kg^{-1} DP)

All the pens were in the same house, and were equipped with two single space feeders and a separate nipple drinker (Figure 2.3, page 61). The pigs were allowed *ad libitum* access to both food and water.

Treatments were allocated randomly to the pens in each block. Each feed was allocated at random to one of the two feeders in each pen. All the feeds were presented as pellets. All the pigs were weighed on three consecutive days each week of the experiment and an average weight for each week was calculated. Feed consumed was recorded for a three day and a four day period each week throughout the experiment.

Twenty four pens were available at any one time, so the experiment was carried out over two time replicates, of twenty four and sixteen pigs.

A fourteen day training period was given at the beginning of the experiment, in which the pigs were allowed access to each of the feeds for alternate twenty four hour periods.

Statistical analysis of the data was performed by analysis of variance of the measured and calculated variables, using the GENSTAT statistical package (Lawes Agricultural Trust, 1984).

2.4.3. Results

Pigs clearly discriminated between the two feeds they were offered, tending to eat one or the other. In the treatments in which a feed with medium low lysine was offered 85% (17 out of 20) ate mostly (> 85%) this feed. In the two treatments with low lysine feeds there was slightly more variation in the diet selected, but 50% (10 out of 20) pigs still preferred to eat mostly the high lysine feed (Figure 2.10). Each treatment offered the same choice between threonine concentrations, but there were clear treatment differences in the diets selected (Figure 2.11).

There was no significant treatment effect on weight gain, feed intake or feed conversion efficiency, although there was a trend for the pigs on the treatments including the medium low lysine feeds to eat more and grow faster (Table 2.19).

The proportion of the high lysine feed consumed was different between treatments except during the training period (Table 2.20), since the pigs offered the low lysine feed tended to prefer the high lysine feed, while those offered the medium low lysine feeds rejected the high lysine feeds. As a result of this the lysine concentration of the diet consumed (Table

FIGURE 2.10. Lysine concentration selected by individual growing pigs on different dietary choices.

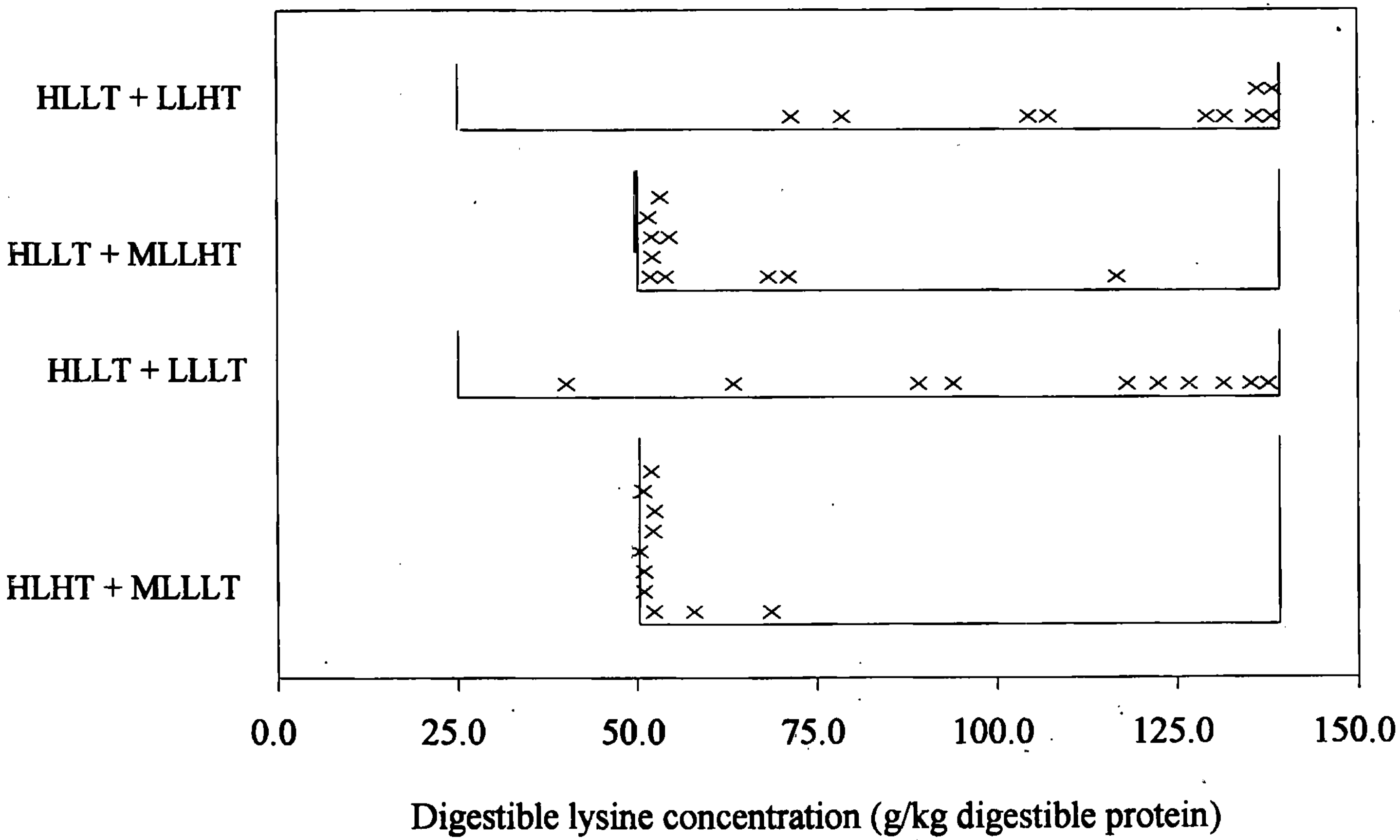


FIGURE 2.11. Threonine concentration selected by individual growing pigs on different dietary choices.

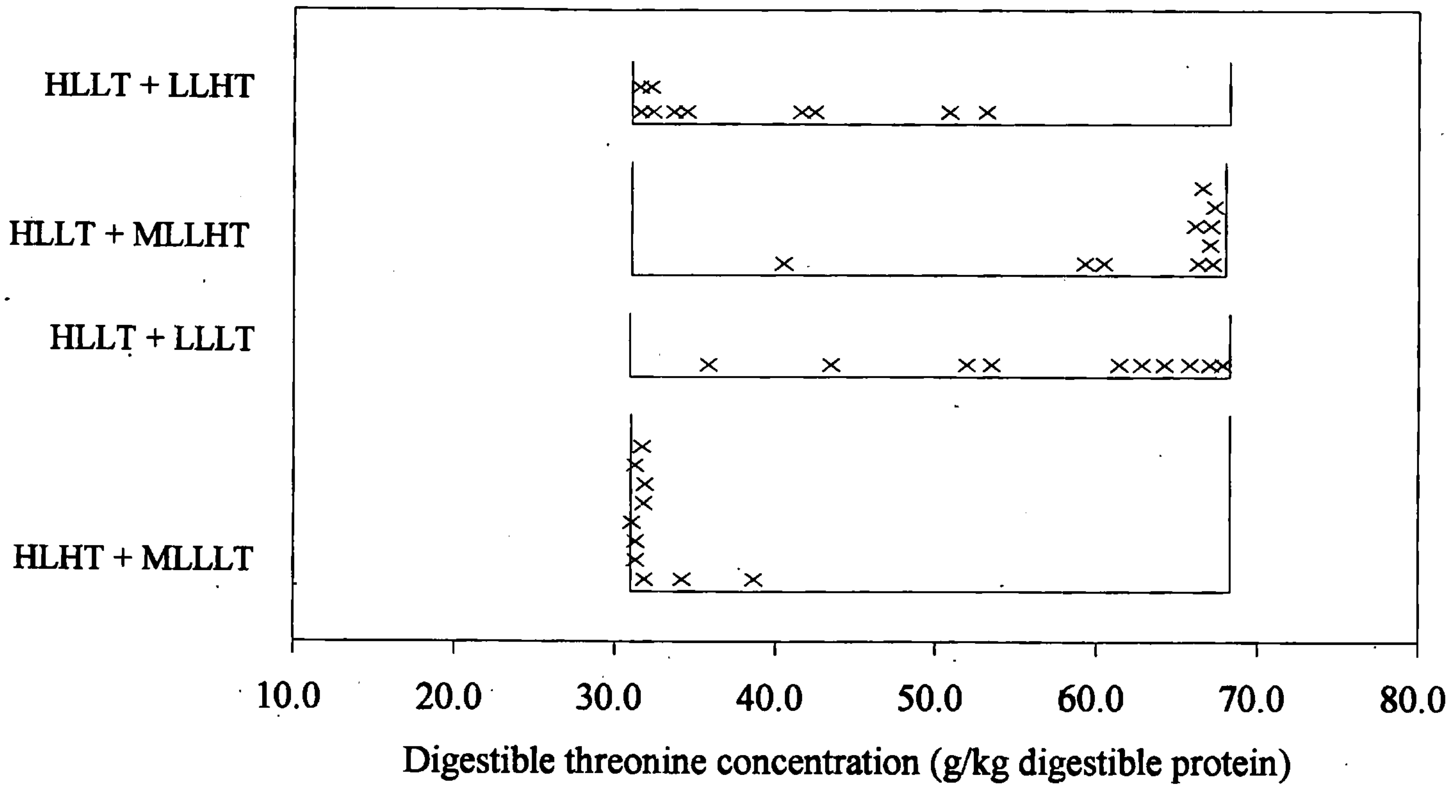


TABLE 2.19. Effect of dietary choice on weight gain,feed intake and feed conversion efficiency.

	Initial Weight (kg)	Weight Gain (kg/day)	Feed Intake (kg/day)	Feed Conversion Efficiency
Choice:	NS	NS	NS	NS
HLLT + LLHT	15.36	0.53	1.09	0.47
HLLT + MLLHT	14.80	0.64	1.20	0.53
HLHT + LLLT	14.27	0.57	1.09	0.52
HLHT + MLLLT	14.95	0.59	1.14	0.51
Mean	14.85	0.58	1.13	0.51
SEM (35 df)	0.594	0.045	0.063	0.023

NS P > 0.05

TABLE 2.20. Effect of dietary choice on the proportion of higher lysine feed consumed.

	Proportion Higher Lysine Feed Consumed			
	Days 1-4 of selection	Days 5-7 of selection	Days 8-11 of selection	Days 12-14 of selection
Choice:				
HLLT + LLHT	0.745	0.847	0.847	0.728
HLLT + MLLHT	0.126	0.127	0.066	0.240
HLHT + LLLT	0.668	0.734	0.669	0.657
HLHT + MLLLT	0.011	0.025	0.060	0.019
Mean	0.387	0.433	0.411	0.411
SEM (35 df)	0.0879	0.0713	0.0681	0.0996

2.21) and the amount of lysine eaten each day (Table 2.22) was different between the treatments during the selection period. The threonine concentration in the diet consumed (Table 2.23) and the amount of threonine eaten each day (Table 2.24) differed between treatments, despite the fact that each treatment offered the same choice of threonine levels.

TABLE 2.21. Effect of dietary choice on the lysine concentration consumed.

	Digestible lysine concentration (g/kg dig. protein)			
	Days 1-4 of selection	Days 5-7 of selection	Days 8-11 of selection	Days 12-14 of selection
Choice:				
HLLT + LLHT	111.6	123.2	123.2	109.7
HLLT + MLLHT	61.7	61.8	56.4	71.9
HLHT + LLLT	103.9	111.4	104.4	102.4
HLHT + MLLLT	51.6	52.9	56.3	52.4
Mean	82.2	87.3	85.1	84.1
SEM (35 df)	9.44	7.41	7.34	10.28

TABLE 2.22. Effect of dietary choice on the amount of lysine consumed.

	Digestible Lysine Consumed (g/day)			
	Days 1-4 of selection	Days 5-7 of selection	Days 8-11 of selection	Days 12-14 of selection
Choice:	**	***	***	*
HLLT + LLHT	22.4	26.5	32.6	28.8
HLLT + MLLHT	13.0	14.1	14.9	20.2
HLHT + LLLT	21.8	25.9	27.1	29.7
HLHT + MLLLT	9.9	10.9	14.9	13.5
Mean	16.8	19.4	22.4	23.1
SEM (35 df)	2.63	2.71	2.85	3.81

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

TABLE 2.23. Effect of dietary choice on threonine concentration consumed.

	Digestible threonine concentration (g/kg dig. protein)			
	Days 1-4 of selection	Days 5-7 of selection	Days 8-11 of selection	Days 12-14 of selection
Choice:				
HLLT + LLHT	40.2	36.4	36.4	40.8
HLLT + MLLHT	63.2	63.1	65.4	59.0
HLHT + LLLT	56.7	59.2	56.9	56.3
HLHT + MLLLT	31.5	32.1	33.5	31.9
Mean	47.9	47.7	48.0	47.0
SEM (35 df)	3.24	2.64	2.50	3.69

TABLE 2.24. Effect of dietary choice on the amount of threonine consumed.

	Digestible threonine consumed (g/day)			
	Days 1-4 of selection	Days 4-7 of selection	Days 7-11 of selection	Days 11-14 of selection
Choice:	***	***	***	**
HLLT + LLHT	7.25	7.50	9.34	10.25
HLLT + MLLHT	13.37	15.08	17.60	16.42
HLHT + LLLT	11.65	13.60	14.42	16.17
HLHT + MLLLT	6.02	6.62	8.81	8.22
Mean	9.57	10.70	12.59	12.76
SEM (35 df)	1.028	1.151	1.325	1.540

** P > 0.01, *** P > 0.001

2.4.4. Discussion

All four treatments presented in this experiment offered the same choice of threonine level, but the selections made by the pigs varied between the treatments. It appears that the pigs have made their dietary choices mainly on the lysine concentration of the feeds offered. However, in comparison with the previous lysine experiment carried out, the pigs offered a choice between high lysine and low lysine feeds did not completely reject the low lysine feed. This suggests that the threonine content of the feeds had a slight effect on the diets selected. In the choice between high and medium low lysine feeds, the pigs almost totally rejected the high lysine feed, regardless of whether it was coupled with high or low threonine concentration. In these two treatments it would appear that threonine concentration had no effect on the resultant diet selected by the pigs. Since the low threonine concentration has been shown in a single-feed experiment not to have any adverse short term effects on the pigs, it would not be expected that threonine concentration would affect the outcome of the experiment in any way.

2.4.5. Conclusions

Growing pigs could detect differences in feeds with differing lysine and threonine concentrations; however, they did not select a mixture of the two feeds choosing instead to eat one or other of the feeds offered. The pigs selected the feeds mainly on the basis of the lysine content of the feeds.

2.5. Selection of dietary protein and lysine concentration by growing pigs.

2.5.1. Introduction

Growing pigs appear to have an ability to select a diet to satisfy their protein requirements from two feeds with differing protein concentrations (Kyriazakis *et al*, 1990). However, when they are offered a choice of two feeds differing only in the level of lysine, threonine or both of these, they tend to eat predominantly one feed, rather than a mixture to satisfy their requirements. If pigs are genuinely able to select a suitable protein concentration, some component of protein must be detected for a pig to be able to assess protein concentration. The most likely component is an essential amino acid; however, neither lysine nor threonine appear to possess this quality. It may be possible to harness a pig's ability to select protein concentration to allow it to select an appropriate lysine concentration by offering it a choice of two feeds differing in both protein and lysine concentration.

The aim of this experiment was to discover if pigs can select a mixture of two feeds that differ in protein concentration, and to examine the effect that imbalancing the protein content of these feeds, by altering the lysine concentration, has on the selections made.

2.5.2. Methods and Materials

(i) Choice-Fed Pigs

A diet selection experiment was conducted at the experimental pig house, Harper Adams Agricultural College, Shropshire. Forty eight male pigs, approximately seven weeks old and with an initial mean weight of 14.5 kg, were allocated at random to one of six treatments consisting of two feeds of differing protein and lysine concentrations.

The six dietary choices provided were:

1. High Protein-Balanced Lysine	+ Low Protein-Balanced Lysine
2. High Protein-Low Lysine	+ Low Protein-Low Lysine
3. High Protein-High Lysine	+ Low Protein-High Lysine
4. High Protein-Low Lysine	+ Low Protein-High Lysine
5. High Protein-High Lysine	+ Low Protein-Low Lysine
6. High Protein-Balanced Lysine	+ Low Protein-Low Lysine

Two basal feeds were formulated: a low protein, low lysine feed with a digestible protein (DP) concentration of 114.8 g kg^{-1} feed and a digestible lysine concentration of 26.0 g kg^{-1} DP, and a high protein, high lysine feed with a DP concentration of 224.0 g kg^{-1} feed and a digestible lysine concentration of 26.0 g kg^{-1} DP. The composition of the basal feeds is shown in Table 2.25. A further two lysine concentrations were formed by adding synthetic lysine to the two basal feeds. The feeds were:

1. Low Protein-Low Lysine (26 g lysine kg^{-1} DP)
2. Low Protein-Balanced Lysine (70.6 g lysine kg^{-1} DP)
3. Low Protein-High Lysine (141.3 g lysine kg^{-1} DP)
4. High Protein-Low Lysine (26.0 g lysine kg^{-1} DP)
5. High Protein-Balanced Lysine (70.0 g lysine kg^{-1} DP)
6. High Protein-High Lysine (140.0 g lysine kg^{-1} DP)

All the pens were in the same house, and were equipped with two single space feeders and a separate drinker (Figure 2.3, page 61). The pigs were allowed *ad libitum* access to both food and water.

Treatments were allocated randomly to the pens in each block. Each feed was allocated at random to one of the two feeders in each pen. All the feeds were presented as pellets. All the pigs were weighed on three consecutive days each week of the trial and an average weight for each

TABLE 2.25. Composition (g/kg feed) and analysis of the basal feeds.

Feed	LPLL	HPLL
Digestible Protein Concentration (g/kg feed)	115	224
Digestible Lysine Concentration (g/kg digestible protein)	26	26
Ingredient		
Wheat	881.75	459.05
Vegetable Oil	24.00	29.00
Sunflower Meal	25.00	236.00
Maize Gluten Meal	25.00	242.00
Lysine	0.50	0.20
Methionine	2.75	0.00
Threonine	2.50	2.25
Salt	3.50	3.50
Dicalcium phosphate	15.00	5.00
Limestone	0.00	3.00
Vits/mins supplement	20.00	20.00
Analysis (calculated unless otherwise stated)		
Total Crude Protein (determined - g N x 6.25/kg)	130.53	268.22
Digestible Protein (g/kg feed)	114.77	224.04
DE (MJ/kg feed)	14.37	14.27
Digestible Lysine (g/kg digestible protein)	26.03	26.00
Digestible Methionine (g/kg digestible protein)	30.24	23.63
Digestible Threonine (g/kg digestible protein)	44.74	41.65

week was calculated. Feed consumed was recorded for a three day and a four day period each week throughout the trial.

Twenty four pens were available at any one time, so the trial was carried out over two time replicates of twenty four pigs.

A fourteen day training period was given at the beginning of the trial, in which the pigs were allowed access to each of the feeds for alternate twenty four hour periods.

Blood samples were taken from the pigs two days before the start of the experiment, on the eighth and eleventh days of the training period and at the end of the selection period. The samples were centrifuged to obtain the serum, which was then analysed for triglyceride and ß-hydroxybutyrate concentration. Methods for these analyses are shown in Appendix B.

(ii) Single-Fed Pigs

An experiment was conducted at the experimental pig house, Harper Adams Agricultural College with twenty four male pigs, approximately nine weeks old and with an initial mean weight of 24.0 kg. Each pig was allocated at random to one of six treatments consisting of each of the single feeds used in the diet selection experiment.

These pigs did not have a training period, so were consequently two weeks older than the choice fed pigs. The experimental procedure was the same as for the choice fed pigs.

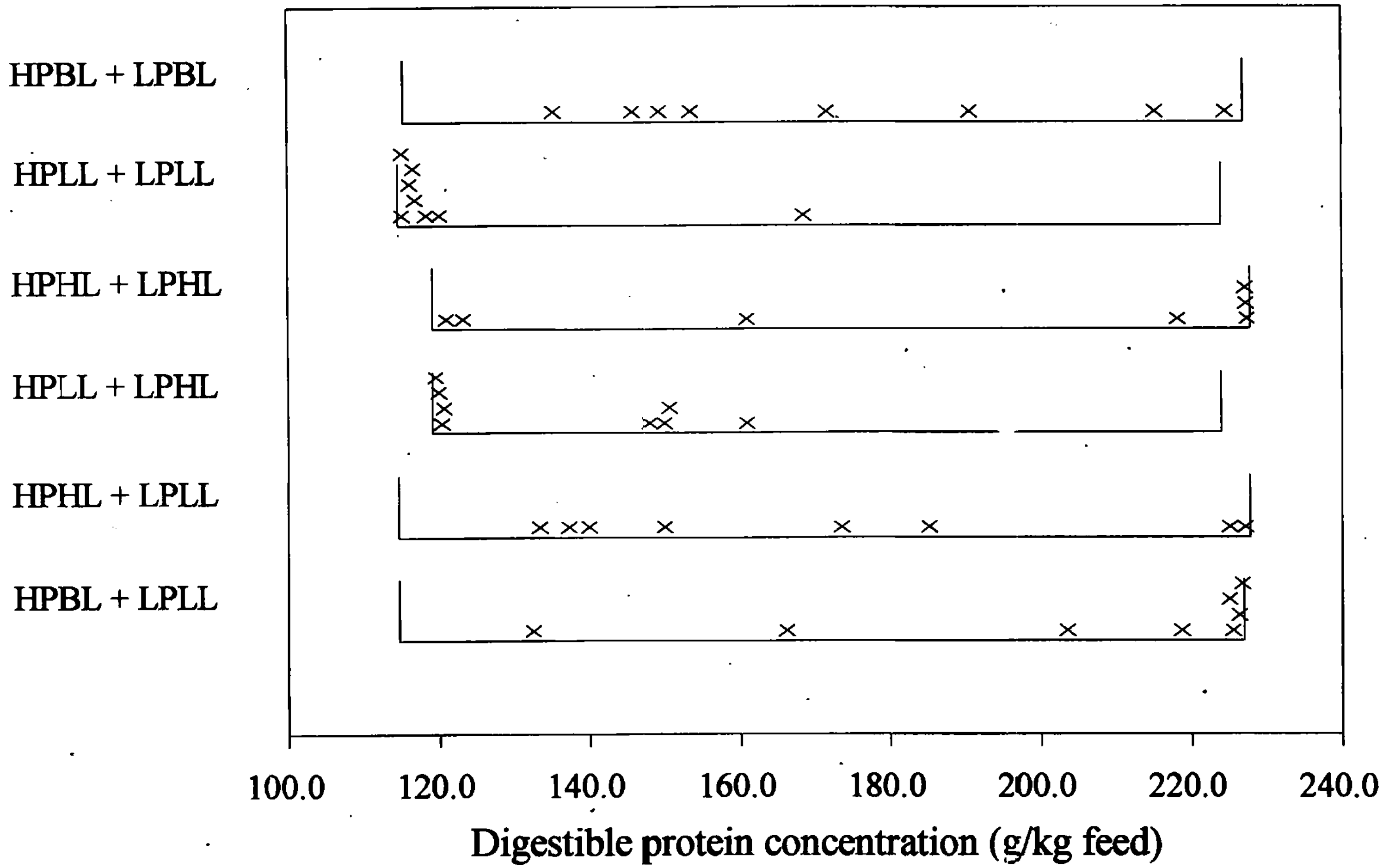
Statistical analysis of the data was performed by analysis of variance of the measured and calculated variables, using the GENSTAT statistical package (Lawes Agricultural Trust, 1984).

2.5.3. Results

(i) Choice Fed Pigs

In the choice between two balanced proteins (High protein, Balanced lysine and low protein, Balanced lysine), nearly all the pigs ate some of each feed. However, the range of digestible protein concentrations selected was between 135 and 240 g kg^{-1} feed, and no two pigs selected the same protein concentration (Figure 2.12). In four of the other five treatments, most pigs ate only one feed, with the high protein, low lysine feed being avoided. However, with the choice of high protein, low lysine and low protein, high lysine, all the pigs ate only the low protein feed at the start of selection, but after a few days half of the pigs started incorporating the high protein feed into their selection. In the choice between high protein, high lysine and low protein, low lysine 75% of the pigs ate from both feeds, but as with the choice of balanced proteins the resulting protein concentrations consumed varied widely between individuals. In the remaining two choices, 73% (11 out of 15) of the pigs ate mostly (> 85%) one feed. More pigs preferred the high protein feed (9 pigs) than the low protein feed (2 pigs) ($P < 0.05$).

FIGURE 2.12. Protein concentration selected by individual growing pigs on different dietary choices.



There was a significant treatment effect on weight gain and feed intake (Table 2.26), with the pigs given the choice between two feeds both with low lysine concentrations growing and eating less, and the pigs on the balanced feeds growing and eating more. Feed conversion efficiency (FCE) was lower in the pigs given two low lysine feeds, and was higher in the pigs on the balanced protein feeds (Table 2.26).

There was a difference in the proportion of the high protein feed consumed between treatments during the training and selection periods (Table 2.27), with pigs on treatments including the high protein, low lysine feed consuming much less of the high protein feed than those on other treatments. This occurred even during the training period where reducing the proportion of one feed eaten would mean reducing daily feed intake on the days that they had access only to the high protein, low lysine feed. As a result of this the protein concentration of the diet consumed (Table 2.28) and the amount of protein eaten each day (Table 2.29) differed between the treatments. The lysine concentration in the diet consumed (Table 2.30) varied considerably between the treatments, as did the amount of lysine eaten each day (Table 2.31).

There was no difference in the serum triglyceride or ß-hydroxybutyrate

TABLE 2.26. Effect of dietary choice on weight gain, feed intake and feed conversion efficiency.

	Initial Weight (kg)	Weight Gain (kg/day)	Feed Intake (kg/day)	Feed Conversion Efficiency
Choice:	NS	***	NS	***
HPBL + LPBL	14.43	0.757	1.300	0.584
HPLL + LPLL	15.04	0.287	0.937	0.312
HPHL + LPHL	14.45	0.638	1.173	0.535
HPLL + LPHL	14.18	0.601	1.129	0.528
HPHL + LPLL	14.59	0.652	1.170	0.555
HPBL + LPLL	14.38	0.640	1.255	0.483
Mean	14.51	0.596	1.161	0.499
SEM (35 df)	0.619	0.0589	0.0808	0.0339

NS $P > 0.05$, ** $P < 0.01$, *** $P < 0.001$

TABLE 2.27. Effect of dietary choice on the proportion of the high protein feed consumed.

	Proportion High Protein Feed Consumed			
	Days 1-4 of selection	Days 5-7 of selection	Days 8-11 of selection	Days 12-14 of selection
Choice:	***	***	**	**
HPBL + LPBL	0.454	0.579	0.466	0.582
HPLL + LPLL	0.047	0.065	0.095	0.106
HPHL + LPHL	0.595	0.640	0.554	0.565
HPLL + LPHL	0.044	0.145	0.198	0.220
HPHL + LPLL	0.473	0.518	0.466	0.539
HPBL + LPLL	0.800	0.842	0.751	0.764
Mean	0.402	0.465	0.422	0.463
SEM (35 df)	0.0985	0.1121	0.1238	0.1139

** $P < 0.01$, *** $P < 0.001$

TABLE 2.28. Effect of dietary choice on protein concentration consumed.

	Digestible protein concentration (g/kg feed)			
	Days 1-4 of selection	Days 5-7 of selection	Days 8-11 of selection	Days 12-14 of selection
Choice:	***	***	**	**
HPBL + LPBL	166.1	180.1	167.5	180.4
HPLL + LPLL	119.9	121.8	125.1	126.3
HPHL + LPHL	183.9	188.8	179.4	180.6
HPLL + LPHL	123.9	134.5	140.0	142.3
HPHL + LPLL	168.3	173.3	167.5	175.8
HPBL + LPLL	204.3	209.3	199.0	200.5
Mean	161.1	168.0	163.1	167.7
SEM (35 df)	10.96	12.43	13.68	12.54

** $P < 0.01$, *** $P < 0.001$

TABLE 2.29. Effect of dietary choice on amount of protein consumed.

	Digestible protein consumed (g/day)			
	Days 1-4 of selection	Days 5-7 of selection	Days 8-11 of selection	Days 12-14 of selection
Choice:	***	***	**	**
HPBL + LPBL	210	229	221	262
HPLL + LPLL	112	109	109	128
HPHL + LPHL	209	216	206	233
HPLL + LPHL	121	137	165	204
HPHL + LPLL	180	188	203	239
HPBL + LPLL	252	249	257	285
Mean	181	188	194	225
SEM (35 df)	16.7	23.2	25.4	28.5

** $P < 0.01$, *** $P < 0.001$

TABLE 2.30. Effect of dietary choice on the lysine concentration consumed.

	Digestible lysine conc. (g/kg digestible protein)			
	Days 1-4 of selection	Days 5-7 of selection	Days 8-11 of selection	Days 12-14 of selection
Choice:	***	***	***	***
HPBL + LPBL	70.1	70.0	70.1	69.9
HPLL + LPLL	26.0	26.0	26.0	26.0
HPHL + LPHL	140.5	140.4	140.5	140.5
HPLL + LPHL	132.5	117.9	109.4	106.8
HPHL + LPLL	93.1	95.6	89.4	97.4
HPBL + LPLL	63.6	63.8	61.2	62.1
Mean	87.6	85.6	82.8	83.8
SEM (35 df)	5.30	8.04	8.38	7.81

*** $P < 0.001$

TABLE 2.31. Effect of dietary choice on amount of lysine consumed.

	Digestible lysine consumed (g/day)			
	Days 1-4 of selection	Days 5-7 of selection	Days 8-11 of selection	Days 12-14 of selection
Choice:	***	***	***	***
HPBL + LPBL	14.7	16.0	15.5	18.3
HPLL + LPLL	2.9	2.8	2.8	3.3
HPHL + LPHL	29.3	30.3	29.0	32.8
HPLL + LPHL	16.2	15.4	16.7	19.8
HPHL + LPLL	17.7	19.5	20.3	25.8
HPBL + LPLL	16.4	16.8	16.8	18.5
Mean	16.2	16.8	16.8	19.8
SEM (35 df)	2.07	2.66	2.92	2.99

*** P < 0.001

concentrations between the treatments (Table 2.32), however, triglyceride concentrations tended to be lower after the experiment and ß-hydroxybutyrate concentration was higher at the end of the experiment.

(ii) Single Fed Pigs

The weight gain of the single fed pigs was different between treatments, with the pigs given low lysine feeds growing least, and those with balanced lysine feeds growing most. Pigs on high protein feeds grew better than those on low protein, except on the low lysine feed (Figure 2.13). Feed intake did not differ between the treatments (Table 2.33), but feed conversion efficiency differed similarly to weight gain. Since the feed was offered in two feeders it was possible to measure how much was eaten from each: 71% of the pigs (17 out of 24) ate mostly (> 85%) from one feeder. This was almost equally divided between the left and the right feeders (Figure 2.14).

TABLE 2.32. Effect of dietary choice on serum triglyceride and B-hydroxybutyrate concentrations.

	Triglyceride Concentration (mg/dL)		B-hydroxybutyrate concentration (mg/dL)		
	Before Experiment	After Experiment	Training Period High Protein Feed	Training Period Low Protein Feed	After Selection
Choice:	NS	NS	NS	NS	NS
HPBL + LPBL	74.9	49.8	0.34	0.74	1.37
HPLL + LPLL	51.7	49.4	0.88	0.47	1.11
HPHL + LPHL	47.2	61.1	0.42	0.43	1.13
HPLL + LPHL	74.9	40.1	0.45	0.74	1.28
HPHL + LPLL	57.4	48.7	0.61	0.69	0.77
HPBL + LPLL	64.9	49.4	0.94	0.24	0.99
Mean	61.8	49.8	0.61	0.55	1.11
SEM (35 df)	15.53	8.25	0.211	0.211	0.289

NS P > 0.05

FIGURE 2.13. Mean weight gain of single-fed pigs with differing protein and lysine concentrations.

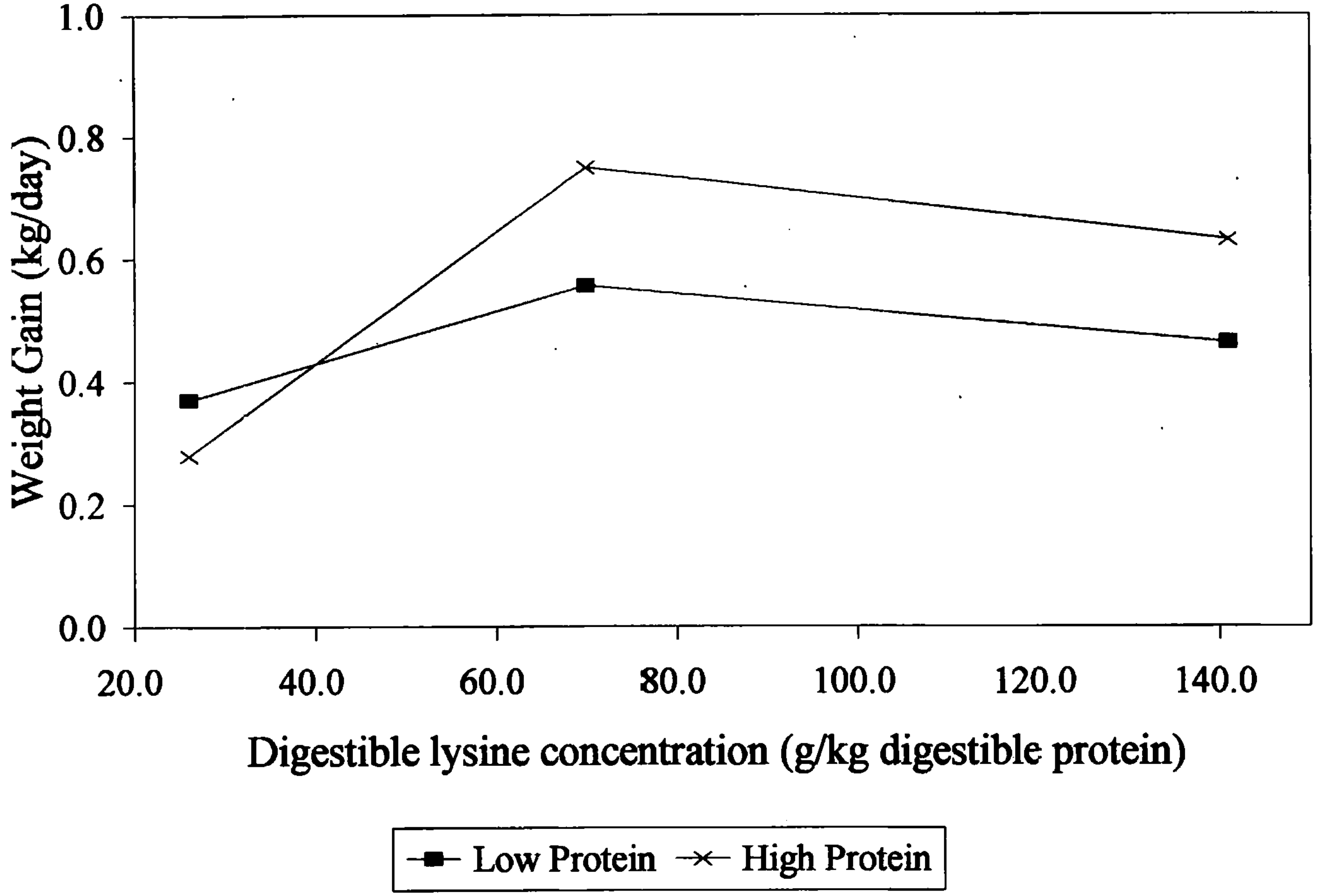
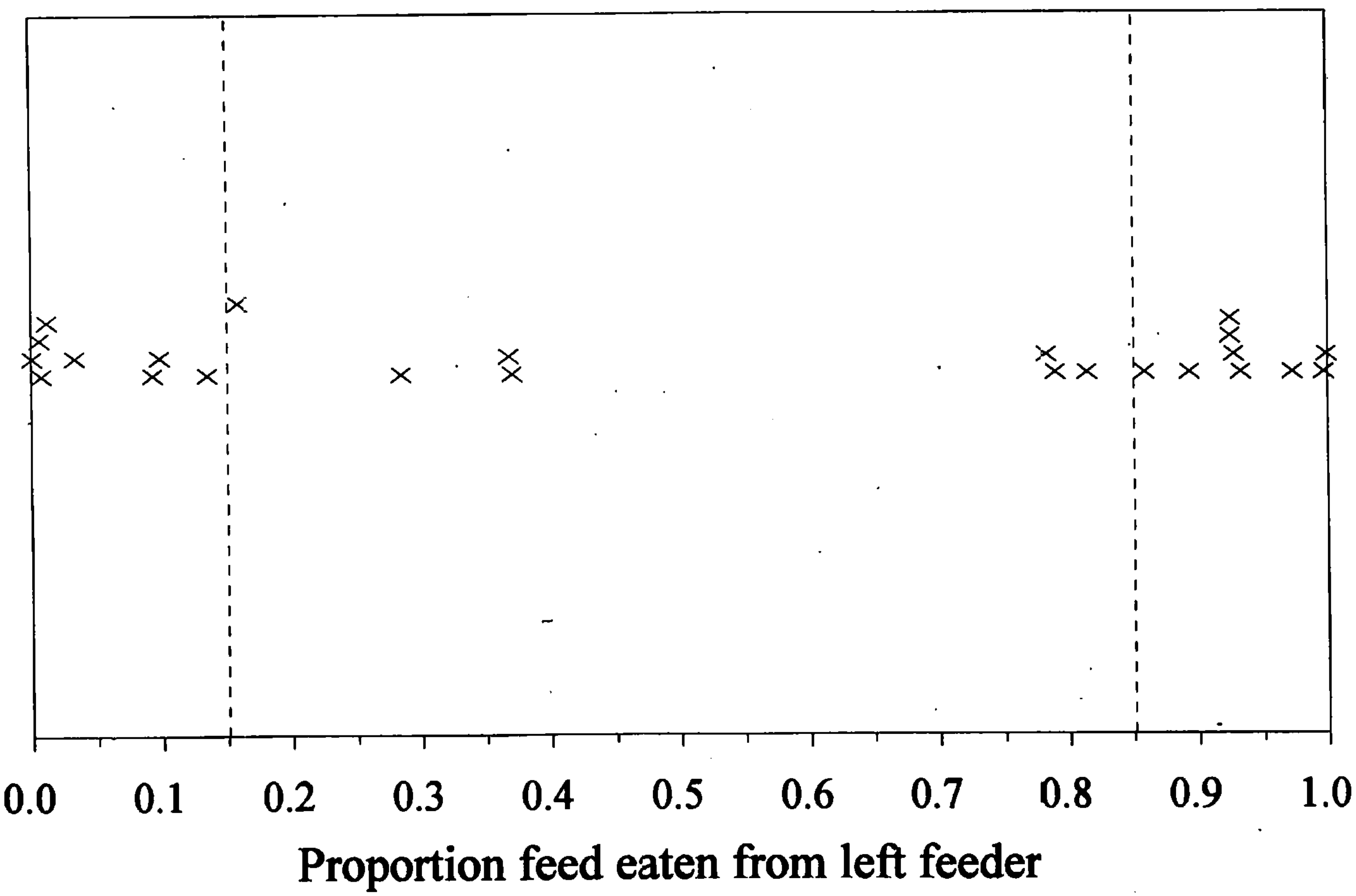


TABLE 2.33. Effect of dietary protein and lysine concentration on weight gain, feed intake and feed conversion efficiency in single-fed pigs.

	Initial Weight (kg)	Weight Gain (kg/day)	Feed Intake (kg/day)	Feed Conversion Efficiency
Treatment:	NS	*	NS	**
LPLL	25.58	0.370	1.309	0.283
LPBL	23.17	0.557	1.241	0.450
LPHL	24.35	0.464	1.130	0.414
HPLL	21.90	0.279	1.155	0.236
HPBL	23.17	0.750	1.364	0.550
HPHL	25.83	0.632	1.571	0.393
Mean	24.00	0.509	1.295	0.387
SEM (15 df)	2.415	0.0967	0.1868	0.0410

NS $P > 0.05$, * $P < 0.05$, ** $P < 0.01$

FIGURE 2.14. *Proportion of feed eaten from the left feeder when both feeders contain the same feed.*



2.5.4. Discussion

When the pigs were given a choice between two feeds of differing protein concentration and the protein was balanced for lysine concentration, they selected a mixture of the two feeds offered, but the resulting protein concentrations selected were so diverse that they were unlikely to be a reflection of their protein requirements. This is in contrast to conclusions of work elsewhere which suggest that pigs have all selected a similar protein concentration that meets their requirements (Kyriazakis *et al*, 1990). When the feeds offered were unbalanced for lysine concentration, most of the pigs ate one or other of the feeds offered, which is similar to previous results found when pigs were offered a choice of feeds differing in lysine concentration. There were two main exceptions to this. Where the choice was between the high protein-high lysine and low protein-low lysine feeds the pigs once again ate a mixture of the two feeds, but as with the balanced feeds, the protein concentrations selected were very diverse. The other exception was the choice between the high protein-low lysine and low protein-high lysine feeds, where all the pigs avoided the high protein feed at the start of selection, but half of the pigs started incorporating this feed into their diet as the experiment went on. This would suggest they did learn that a mixture of the two feeds was better for them than either feed alone, although they did not appear to learn this in the training period. The resulting lysine concentration selected by these four pigs started at 125 g kg^{-1} digestible protein and reduced to 73 g kg^{-1} digestible protein at the end of the experiment, which is very close to the concentration of 70 g kg^{-1} protein recommended by the Agricultural Research Council. However, this may have been related to the length of the experiment, as the lysine concentration may have continued to fall below this level if the experiment had been continued.

In the single-fed pigs feed was offered in two feeders, but all of the pigs preferred to eat from one or other of the feeders. There was no particular position preference; half the pigs preferred the right hand feeder and half the pigs preferred the left hand feeder. Presumably these preferences arose from small variations in the pen such as draughts, lights, aromas etc., but could also be an expression of an innate preference (such as right-handedness in humans). It is possible that this preference for a particular feeder had an effect on the diets selected by pigs on choice treatments. For instance this could explain why, in some treatments, some pigs ate mainly one of the feeds and other pigs ate mainly the other feed. The choice between the two high lysine feeds is such an example, where four pigs ate mainly the high protein feed and two ate mainly the low protein feed. Feeder preference might also explain why only half the pigs in the choice between high protein-low lysine and low protein-high lysine started to select a mixture of the two feeds. The high protein feed, which was not preferred may have been in the feeder they would prefer to eat from, so that they continued to eat a small amount from this feeder, and in this way discovered the beneficial effects of eating both feeds.

Oxidation of some amino acids gives rise to ketones - acetyl CoA and acetoacetyl CoA. Acetyl CoA and acetoacetyl CoA combine with water to form 3-hydroxy-3-methylglutaryl CoA and CoA, which is cleaved to form acetoacetate and acetyl CoA. Acetoacetate is reduced to form ß-hydroxybutyrate. Thus, measurement of ß-hydroxybutyrate concentration gives an indication of the amount of ketones present in the serum. If there are excess amino acids in the feed pigs would tend to have higher ß-hydroxybutyrate concentrations. However, in this experiment ß-hydroxybutyrate concentrations were higher at the end of the selection period than during the training period, suggesting that the pigs were not selecting feeds to minimise the amount of excess amino acids consumed.

2.5.5. Conclusion

The pigs did discriminate between feeds with different protein and lysine concentrations, although less than half the pigs selected a mixture of the two feeds offered, and those that did selected a range of protein concentrations so diverse that it seems unlikely to be a reflection of their protein requirements.

2.6. The effect of positional preferences on the selection of dietary protein and lysine concentration by growing pigs.

2.6.1. Introduction

In the previous experiment it was discovered that pigs fed the same feed in a choice of two feeders have a marked preference for eating out of one of the feeders. This preference may affect the selections made by pigs on dietary choice experiments. To investigate the effect of feeder preference on diet selections made, an experiment was set up to discover the preferred feeder of individual pigs and then discover if putting the feeds on offer either in the preferred or unpreferred feeder had any effect on the selections made.

2.6.2. Methods and materials

A diet selection experiment was conducted at the experimental pig house, Harper Adams Agricultural College, Shropshire. Twenty-four male pigs, approximately seven weeks old and with an initial mean weight of 15.4 kg, were allocated at random to one of two choice treatments, both consisting of the same two feeds.

The two treatments were:

1. Preferred feed in preferred feeder
2. Preferred feed in unpreferred feeder

Three feeds were formulated: a low protein, high lysine feed with a digestible protein (DP) concentration of 114.8 g kg^{-1} feed and a digestible lysine concentration of 141.0 g kg^{-1} DP, a high protein, low lysine feed with a DP concentration of 224.0 g kg^{-1} feed and a digestible lysine concentration of 26.0 g kg^{-1} DP, and a balanced feed with a digestible protein concentration of 171 g kg^{-1} feed and a digestible lysine concentration of 71 g kg^{-1} digestible protein. The composition of the feeds is shown in Table 2.34.

TABLE 2.34. Composition (g/kg feed) and analysis of the feeds.

Feed	LPHL	HPLL	Balanced
Digestible Protein Concentration (g/kg feed)	119	224	171
Digestible Lysine Concentration (g/kg digestible protein)	141	26	71
Ingredient			
Wheat	881.75	459.05	666.35
Vegetable Oil	24.00	29.00	27.99
Sunflower Meal	10.00	236.00	145.35
Maize Gluten Meal	6.50	242.00	110.35
Maize Starch	15.50	0.00	0.00
Lysine	18.50	0.20	10.34
Methionine	2.75	0.00	1.23
Threonine	2.50	2.25	2.46
Salt	3.50	3.50	3.65
Dicalcium phosphate	15.00	5.00	9.66
Limestone	0.00	3.00	1.79
Vits/mins supplement	20.00	20.00	20.84
Analysis (calculated unless otherwise stated)			
Crude Protein (determined - g N x 6.25/kg)	141.45	268.22	209.67
Digestible Protein (g/kg feed)	119.25	224.04	171.34
DE (MJ/kg feed)	14.6	14.27	14.28
Digestible Lysine (g/kg digestible protein)	141.31	26.00	71.12
Digestible Methionine (g/kg digestible protein)	26.34	23.63	23.88
Digestible Threonine (g/kg digestible protein)	39.35	41.65	41.06

For the first half of the experiment all the pigs were given the balanced feed in both feeders to determine feeder preference. There was an eight day training period at the beginning of this period, in which the pigs were allowed access to each of the feeders for alternate twenty four hour periods. For the next fourteen days the pigs were given *ad libitum* access to both feeders. At the end of this period the proportion of feed eaten from each feeder was calculated and the preferred feeder of each pig was discovered.

For the second half of the experiment the pigs were allocated at random to one of two treatments each consisting of a choice between the low protein, high lysine feed and the high protein, low lysine feed. In the previous experiment it was discovered that pigs on this choice preferred the low protein feed, although half the pigs did learn to select a mixture of the two feeds. A second eight day training period was given in which the pigs were allowed access to each of the feeds for alternate twenty four hour periods. The pigs were given *ad libitum* access to both feeds for the next fourteen days.

All the pens were in the same house, and were equipped with two single space feeders and a separate nipple drinker (Figure 2.3, page 61). The pigs were allowed *ad libitum* access to both food and water.

All the feeds were presented as pellets. All pigs were weighed on three consecutive days each week of the experiment and an average weight for each week was calculated. Feed consumed was recorded for a three day and a four day period each week throughout the experiment. All the feeds were presented as pellets.

Statistical analysis of the data was performed by analysis of variance of the measured and calculated variables, using the GENSTAT statistical package (Lawes Agricultural Trust, 1984).

2.6.3. Results

During the first selection period all of the pigs ate more from one feeder than from the other, although some pigs did not have very strong preferences (Figure 2.15). Twelve pigs preferred the left-hand feeder and twelve pigs preferred the right-hand feeder.

In the second selection period most of the pigs on both treatments ate mainly the preferred feed (low protein, high lysine) (Figure 2.16). Weight gain, feed intake and feed conversion efficiency (FCE) did not differ between the treatments, except for feed intake in the second training period, where the pigs with the preferred feed in the preferred feeder ate less than the other pigs (Tables 2.35, 2.36 and 2.37). The proportion of feed consumed from the preferred feeder was not different between the treatments when the feed was the same in both feeders. After the choice of feeds was given there was a marked difference in the proportion of feed eaten from the preferred feeder, with the pigs given their preferred feed in their preferred feeder eating mainly from the preferred feeder, and the pigs given their preferred feed in their unpreferred feeder eating mainly from the unpreferred feeder (Table 2.38).

FIGURE 2.15. The proportion of feed consumed from the left feeder when both feeders contain the same feed.

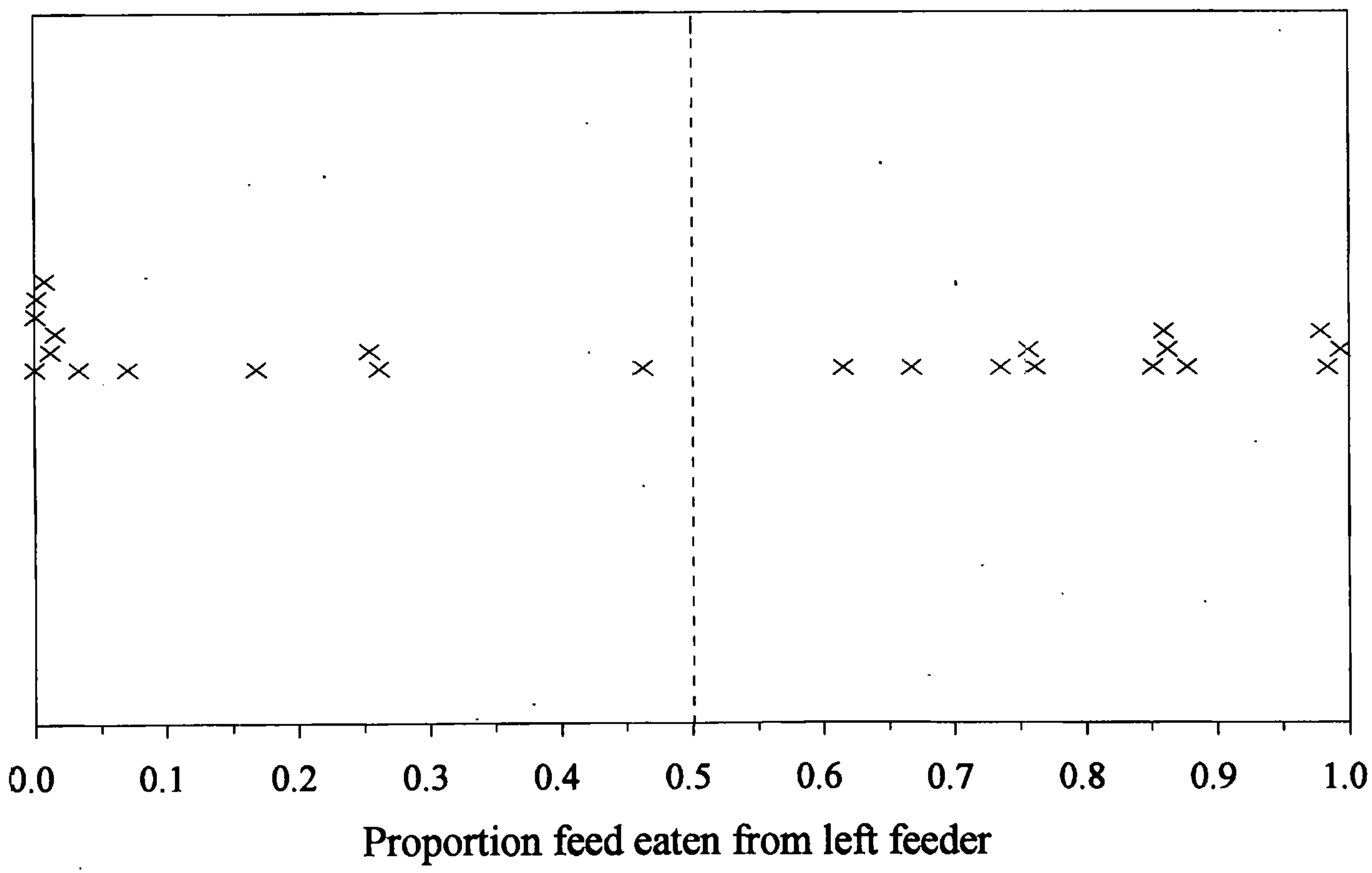


FIGURE 2.16. Protein concentration selected by individual growing pigs during the second selection period.

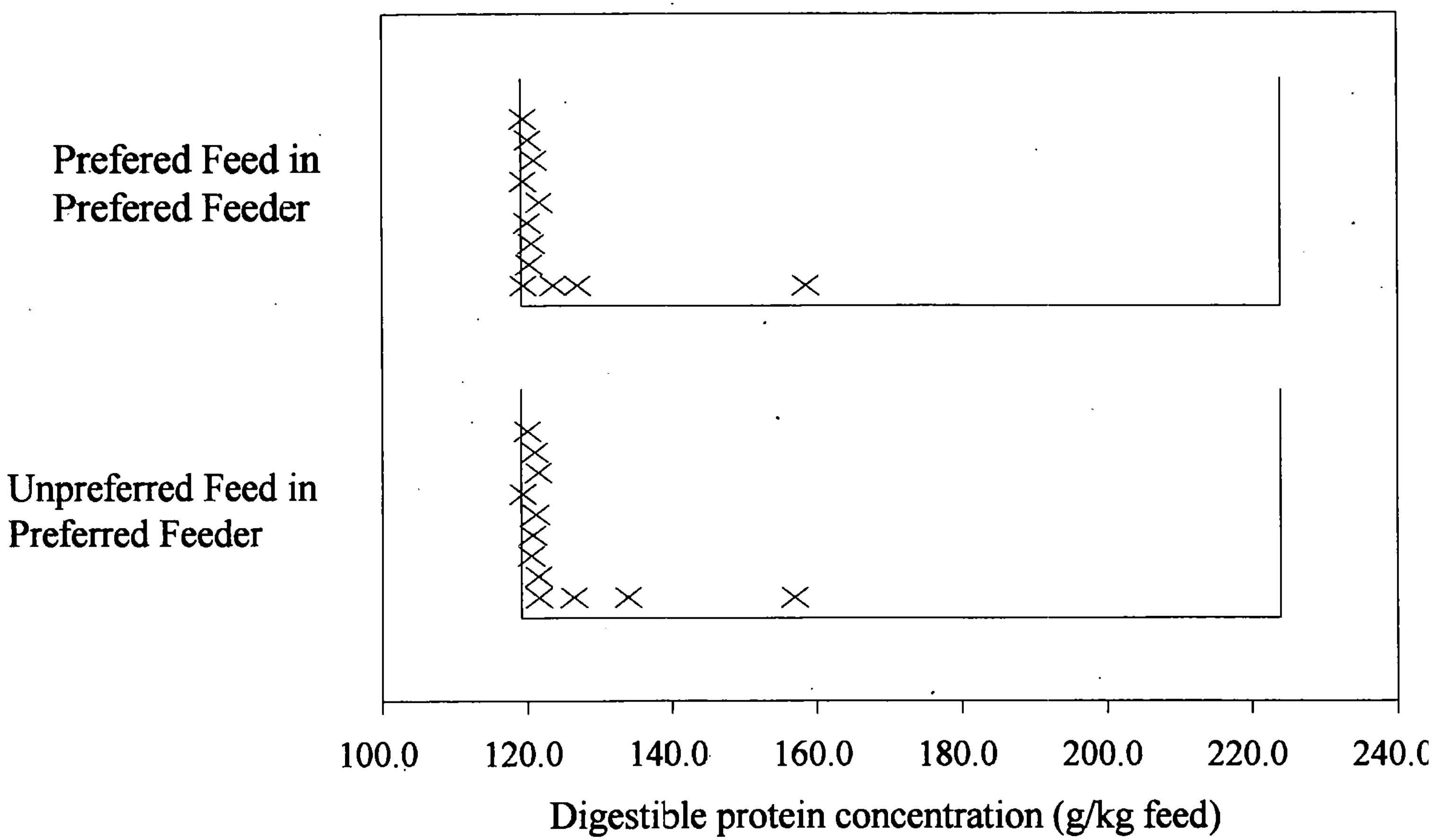


TABLE 2.35. Effect of treatment on weight gain.

	Initial Weight (kg)	Weight Gain (kg/day) First Training Period	First Selection Period	Second Training Period	Second Selection Period
Choice:	NS	NS	NS	NS	NS
Preferred Feed in Preferred Feeder	15.18	0.55	0.68	0.45	0.70
Preferred Feed in Unpreferred Feeder	15.55	0.54	0.72	0.52	0.72
Mean	15.36	0.55	0.70	0.48	0.71
SEM (19 df)	0.438	0.030	0.037	0.052	0.053

NS P > 0.05

TABLE 2.36. Effect of treatment on feed intake.

	Feed Intake (kg/day)			
	First Training Period	First Selection Period	Second Training Period	Second Selection Period
Choice:	NS	NS	*	NS
Preferred Feed in Preferred Feeder	0.89	1.26	1.40	1.67
Preferred Feed in Unpreferred Feeder	0.88	1.35	1.59	1.78
Mean	0.88	1.30	1.49	1.73
SEM (19 df)	0.041	0.050	0.065	0.084

NS P > 0.05, * P < 0.05

TABLE 2.37. Effect of treatment on feed conversion efficiency.

	Feed Conversion Efficiency			
	First Training Period	First Selection Period	Second Training Period	Second Selection Period
Choice:	NS	NS	NS	NS
Preferred Feed in Preferred Feeder	0.62	0.54	0.33	0.41
Preferred Feed in Unpreferred Feeder	0.62	0.54	0.33	0.40
Mean	0.62	0.54	0.33	0.41
SEM (19 df)	0.027	0.015	0.035	0.022

NS $P > 0.05$

TABLE 2.38. Effect of treatment on proportion of feed consumed from the preferred feeder.

	Proportion feed consumed from the preferred feeder			
	First Training Period	First Selection Period	Second Training Period	Second Selection Period
Choice:	NS	NS	***	***
Preferred Feed in Preferred Feeder	0.52	0.87	0.67	0.96
Preferred Feed in Unpreferred Feeder	0.49	0.85	0.35	0.06
Mean	0.50	0.86	0.51	0.51
SEM (19 df)	0.014	0.043	0.028	0.029

NS P > 0.05, *** P < 0.001

2.6.4. Discussion

Feeder preference is obviously a strong motivation for eating from a particular feeder, as all the pigs did display a feeder preference. However, in the choice treatment offered, feeder preference did not play any part in the diet selected. It is possible that with feeds with less difference between them, feeder preference may play a more important part in the resulting diet selected.

2.6.5. Conclusion

Pigs had a preference to eat from one feeder when offered a choice of the same feed in two feeders. However, this preference did not affect the selections they make when given a choice between a high protein, low lysine feed and a low protein, high lysine feed. It appeared that feed preference is more important than feeder preference.

2.7. Selection of dietary tryptophan concentration by growing pigs.

2.7.1. Introduction

Previous experiments have shown that growing pigs can discriminate between two feeds with different lysine and threonine concentrations, but they did not eat a balance of the two feeds appropriate to their needs. Instead the pigs chose to eat mainly the single feed more suitable for their needs. However, it has been reported that they can select an appropriate mixture of two feeds to meet their protein requirements (Kyriazakis *et al*, 1990), which would suggest that they are capable of monitoring some aspect of protein and using this to select an appropriate protein concentration.

Tryptophan is a precursor of 5-hydroxytryptamine which has been implicated in the control of food intake (Fernstrom, 1985). This suggests that the intake of tryptophan may be more closely regulated than that of either lysine or threonine.

The concentration of tryptophan in the ideal protein for pigs has been recommended to be 10 g kg^{-1} protein (ARC, 1981). Most other estimates are slightly higher than this, up to around 14 g kg^{-1} protein (Zhang *et al*, 1984). The NRC (1988) recommend 0.14% in a 15% crude protein diet, for 20-50 kg pigs, which is 8 g kg^{-1} protein.

The objective of this trial was to discover if growing pigs offered two feeds differing only in their tryptophan contents could select an optimal concentration of tryptophan for growth.

2.7.2. Methods and materials

(i) Choice-Fed Pigs

A diet selection experiment was conducted at the experimental pig house, Harper Adams Agricultural College, Shropshire. Forty-eight male growing pigs, approximately seven weeks old and with an initial mean weight of 14.5 kg, werc allocated to one of four dietary choice treatments, each treatment consisting of two feeds of differing tryptophan concentration.

The four dietary choices provided were:

1. High tryptophan	+	Low tryptophan
2. High tryptophan	+	Medium Low tryptophan
3. Medium High tryptophan	+	Low tryptophan
4. Medium High tryptophan	+	Medium Low tryptophan

A basal tryptophan-deficient feed was formulated, with a digestible protein content of 164 g kg^{-1} feed and a digestible tryptophan concentration of 4.4 g kg^{-1} digestible protein. This feed was supplemented with synthetic tryptophan to form four feeds with tryptophan concentrations of 4.4 g (low tryptophan), 7.2 g (medium low tryptophan), 15.0 g (medium high tryptophan) and 20.3 g (high tryptophan) kg^{-1} digestible protein. The composition of the low tryptophan feed is shown in Table 2.39.

All the pens were in the same house, and were equipped with two single space feeders and a separate nipple drinker (Figure 2.3, page 61). The pigs were allowed *ad libitum* access to both food and water.

Treatments were allocated randomly to the pens in each block. Each feed was allocated at random to one of the two feeders in each pen. All the feeds were presented as pellets. All pigs were weighed on three consecutive days each week of the experiment and an average weight for each week was calculated. Feed consumed was recorded for a three day and a four day period each week throughout the experiment. Twenty four pens were available at any one time, so the experiment was carried out over two time replicates.

A fourteen day training period was given at the beginning of the experiment, in which the pigs were allowed access to each of the feeds

TABLE 2.39. Composition (g/kg feed) and analysis of the basal feed.

Feed	Low Tryptophan
Digestible Tryptophan Concentration (g/kg digestible protein)	4.4
Ingredient	
Maize	720.86
Meat and Bone Meal	244.02
Vits/Mins	19.92
Lysine	5.98
Maize Starch	4.00
Threonine	2.74
Methionine	2.49
Analysis (calculated unless otherwise stated)	
Total Crude Protein (determined gN x 6.25/kg feed)	175.2
Digestible Protein (g/kg feed)	128.6
DE (MJ/kg feed)	14.55
Digestible Tryptophan (g/kg digestible protein)	4.43
Digestible Lysine (g/kg digestible protein)	69.0
Digestible Methionine (g/kg digestible protein)	25.0
Digestible Isoleucine (g/kg digestible protein)	27.4

for alternate twenty four hour periods. In a previous experiment looking at selection for feeds differing in lysine concentration, a fourteen day training period was found to be more effective than the eight day training period used in protein experiments (eg Bradford and Gous, 1991).

(ii) Single-Fed Pigs

An experiment was conducted at the experimental pig house, Harper Adams Agricultural College, Shropshire with twenty-four male growing pigs, approximately nine weeks old and with an initial mean weight of 18.9 kg. Each pig was allocated at random to one of six dietary treatments, each consisting of a single feed. The four feeds described above were used, with two additional intermediate feeds to allow better investigation of the growth response to added synthetic tryptophan in the base feed.

1. Low	4.4 g kg^{-1} digestible protein
2. Medium Low	7.2 g kg^{-1} digestible protein
3. Intermediate Low	8.6 g kg^{-1} digestible protein
4. Intermediate High	12.5 g kg^{-1} digestible protein
5. Medium High	15.0 g kg^{-1} digestible protein

6. High 20.3 g kg^{-1} digestible protein

Pigs were given *ad libitum* access to the feed in two identical single space feeders in each pen. Water was available *ad libitum* from two water troughs at the front of the pen.

All the pens in the experimental house were used. Treatments were allocated randomly to the pens in each block. All the pigs were weighed three consecutive days every week and a mean value calculated. Feed consumed was recorded for a three day and a four day period each week throughout the experiment. There was no training period so to allow a comparison of data, these pigs were two weeks older than the choice-fed pigs at the start of thc experiment. The experiment lasted fourteen days.

Statistical analysis of both experiments data was performed by analysis of variance of the measured and calculated variables, using the GENSTAT statistical package (Lawes Agricultural Trust, 1984).

2.7.3. Results

(i) Choice-fed Pigs

The pigs clearly discriminated between the two feeds offered (Figure 2.17). 65% of the pigs ate mostly (> 85%) one feed. Where the choice included the Low tryptophan feed, most pigs (16 out of 24) rejected this in favour of either the High or Medium high tryptophan feed. However, in the choice between the high and the medium low tryptophan feeds, 7 out of 12 pigs preferred feed ML, but two pigs ate mostly H and the remaining three pigs ate from both feeds. In the choice between the medium high and medium low tryptophan feeds, pigs made a range of selections from eating all of the medium low tryptophan feed to eating all of the medium high tryptophan feed.

There was no significant difference between the choice treatments in initial weight or weight gain (Table 2.40), although pigs on the high plus medium low tryptophan choice tended to grow more slowly than pigs on the other treatments. These pigs also tended to eat less than pigs on other treatments (Table 2.40), but once again there was no significant difference. Feed conversion efficiency (FCE) was not different between

FIGURE 2.17. Tryptophan concentration selected by individual growing pigs on different dietary choices.

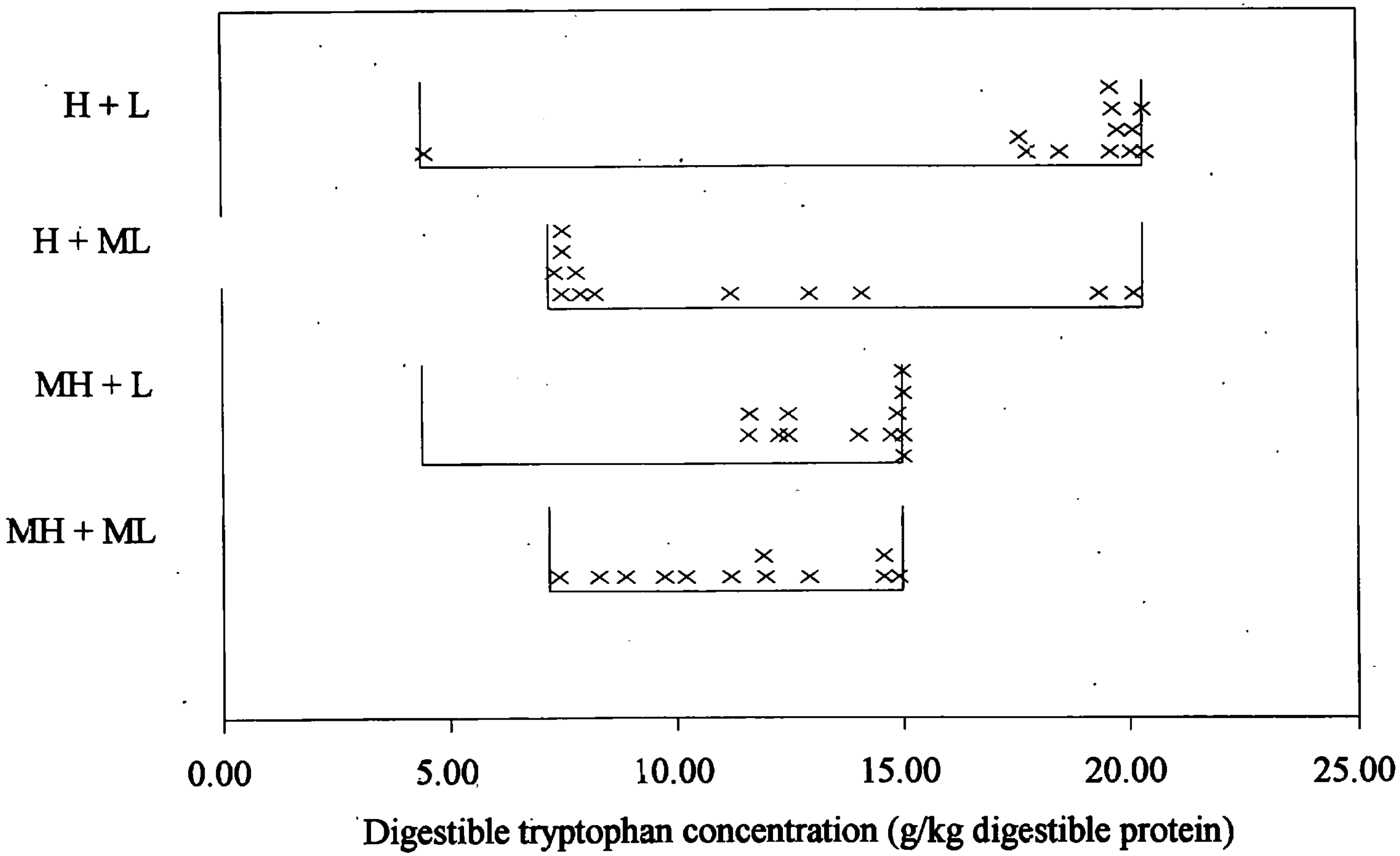


TABLE 2.40. Effect of dietary choice treatment on weight gain, feed intake and feed conversion ratio.

	Initial Weight (kg)	Weight Gain (kg/day)	Feed Intake (kg/day)	Feed Conversion Efficiency
Choice:	NS	NS	NS	NS
High + Low	15.2	0.46	1.25	0.37
High + Medium Low	14.0	0.33	1.03	0.31
Medium High + Low	14.3	0.39	1.11	0.35
Medium High + Medium Low	14.4	0.43	1.29	0.33
Mean	14.5	0.40	1.17	0.34
SEM (33 df)	0.59	0.045	0.089	0.028

NS $P > 0.05$

the treatments (Table 2.40).

There was a difference between the proportions of the higher tryptophan feed consumed (Table 2.41). For pigs given the choice between high plus low tryptophan and medium high plus low tryptophan ate more than 0.85 of their diet was the higher tryptophan feed, while for pigs given the choice between high plus medium low tryptophan less than 0.30 of their diet was the higher tryptophan feed. For pigs given the choice between medium high plus medium low tryptophan the mean proportion of the higher tryptophan feed eaten was less than 0.6, but there was a great deal of individual variation on this treatment.

The tryptophan concentration consumed differed between treatments (Table 2.42), as did the amount of tryptophan consumed (Table 2.43). The pigs on the choice between the high plus low tryptophan feeds consumed a higher tryptophan concentration and more tryptophan than the pigs on the other treatments.

(ii) Single-fed Pigs

The relationship between weight gain and tryptophan concentration in the

TABLE 2.41. The effect of dietary choice treatment on proportion of higher tryptophan feed consumed.

	Proportion Higher Tryptophan Feed Consumed			
	Days 1-4 of selection	Days 5-7 of selection	Days 8-11 of selection	Days 12-14 of selection
Choice:				
High + Low	0.84	0.89	0.83	0.88
High + Medium Low	0.20	0.24	0.28	0.41
Medium High + Low	0.88	0.91	0.90	0.85
Medium High + Medium Low	0.56	0.53	0.45	0.52
Mean	0.61	0.64	0.61	0.67
SEM (33 df)	0.085	0.090	0.111	0.116

TABLE 2.42. The effect of dietary choice treatment on the tryptophan concentration consumed.

	Digestible tryptophan conc. (g/kg dig. protein) Days 0-4 of selection	Days 5-7 of selection	Days 8-11 of selection	Days 12-14 of selection
Choice:				
High + Low	17.43	18.69	17.67	18.47
High + Medium Low	9.91	10.41	10.99	12.72
Medium High + Low	13.77	14.08	13.99	13.43
Medium High + Medium Low	11.66	11.43	10.74	11.34
Mean	13.19	13.65	13.35	13.99
SEM (33 df)	1.074	1.104	1.324	1.363

TABLE 2.43. The effect of dietary choice treatment on the amount of tryptophan consumed.

	Digestible Tryptophan Consumed (g/day)			
	Days 0-4 of selection	Days 5-7 of selection	Days 8-11 of selection	Days 12-14 of selection
Choice:	**	**	*	**
High + Low	3.20	4.06	3.73	4.67
High + Medium Low	1.55	1.65	1.66	2.54
Medium High + Low	2.53	2.28	2.46	2.72
Medium High + Medium Low	1.92	2.58	2.72	2.78
Mean	2.30	2.64	2.65	3.18
SEM (33 df)	0.303	0.400	0.439	0.453

* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

single-fed pigs was non-linear, and reached an asymptote at 8.2 g digestible tryptophan kg^{-1} digestible protein (Figure 2.18). There was no difference between treatments in feed intake or FCE; there was a highly signicant difference between treatments in the amount of tryptophan consumed (Table 2.44).

FIGURE 2.18. Weight gain of single-fed pigs fed differing tryptophan concentrations.

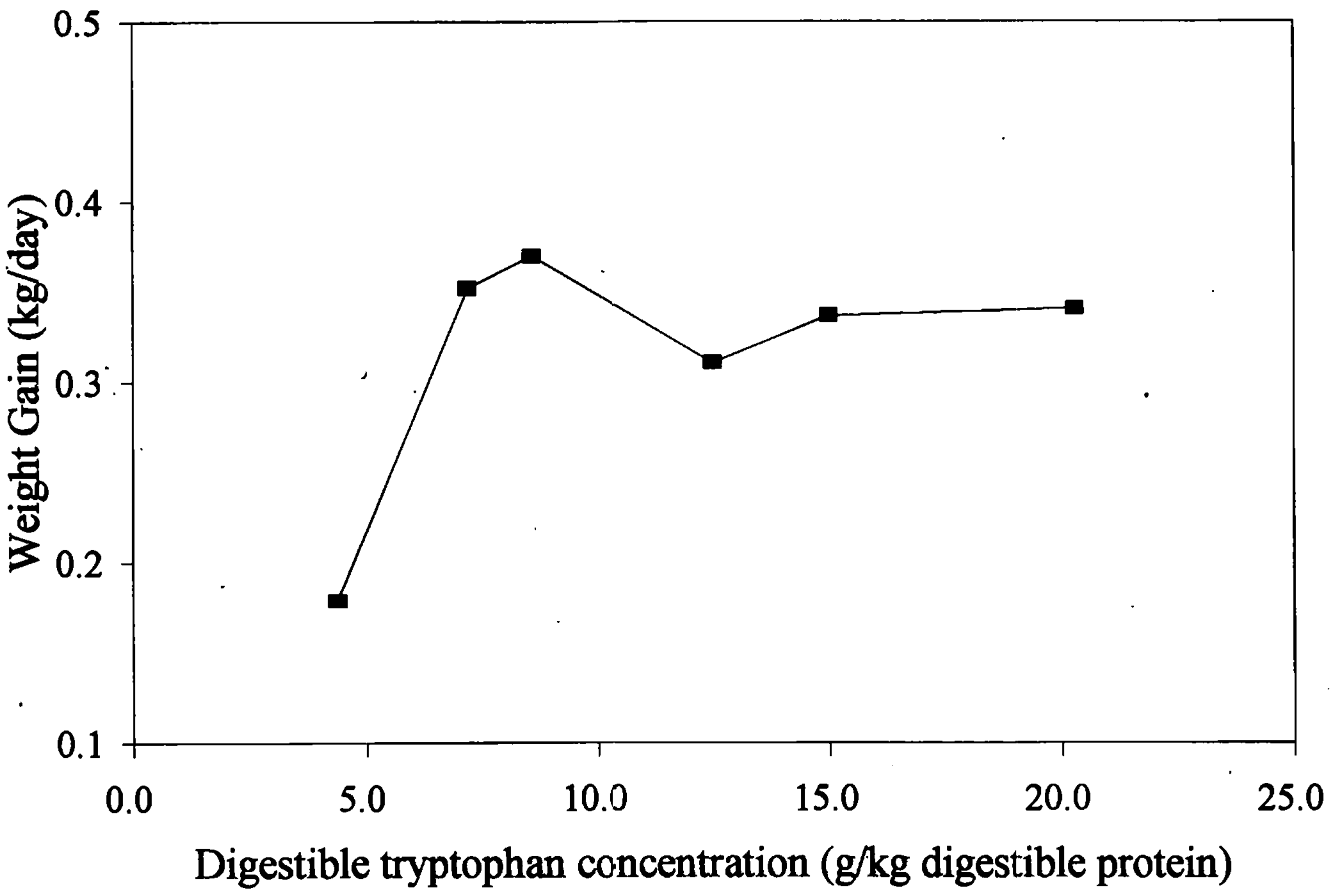


TABLE 2.44. Effect of dietary tryptophan concentration on weight gain, feed intake, feed conversion efficiency and amount tryptophan consumed.

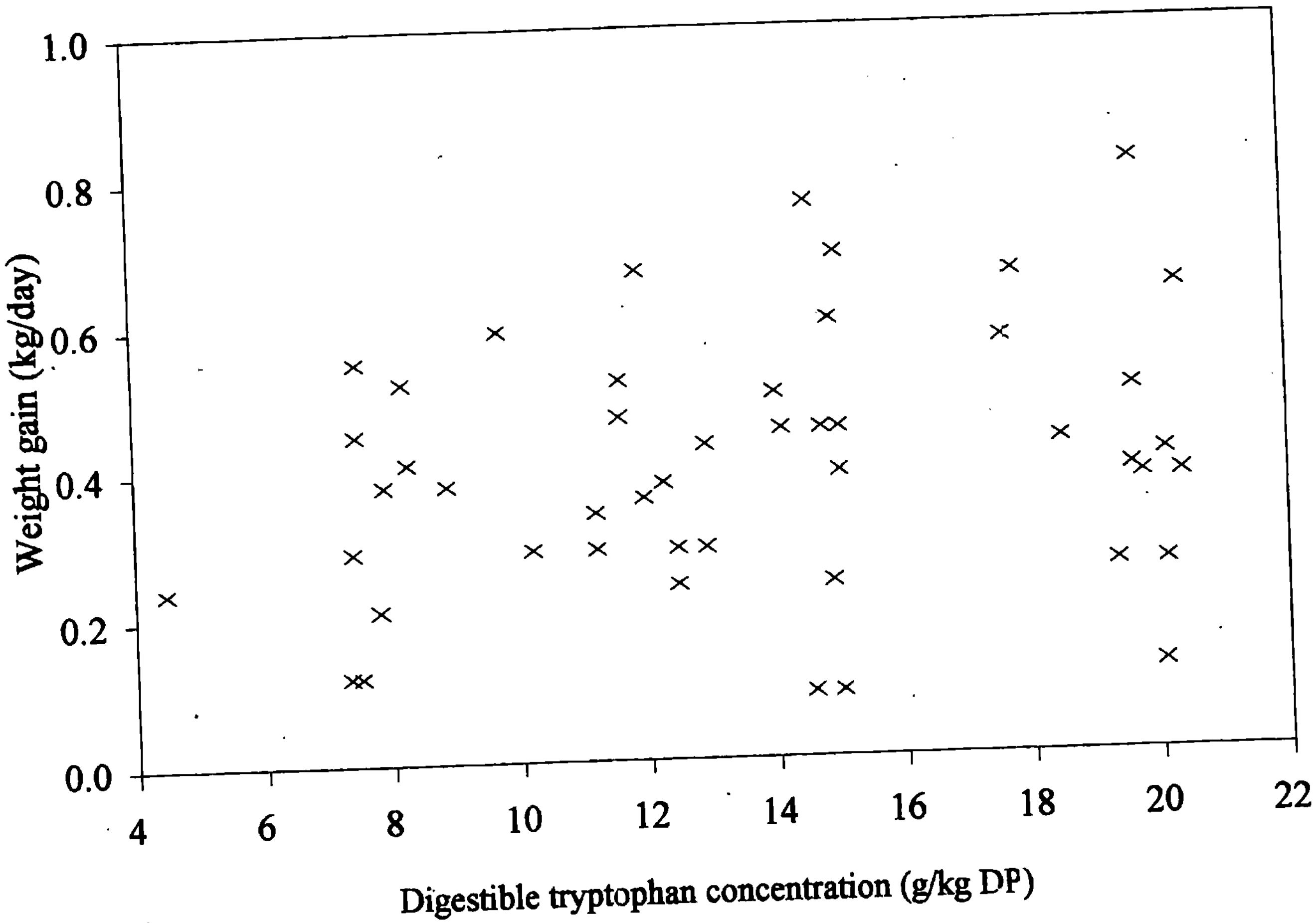
	Initial Weight (kg)	Weight Gain (kg/day)	Feed Intake (kg/day)	Feed Conversion Efficiency	Tryptophan Consumed (g/day)
Digestible Tryptophan Concentration: (g/kg digestible protein)	NS	NS	NS	NS	***
4.4	19.1	0.18	0.86	0.21	0.6
7.2	19.2	0.35	1.24	0.29	1.5
8.6	18.8	0.37	1.05	0.35	1.5
12.5	17.8	0.31	1.01	0.32	2.1
15.0	19.6	0.34	1.01	0.34	2.5
20.3	19.2	0.34	0.88	0.38	3.0
Mean	18.9	0.32	1.01	0.31	1.9
SEM (15 df)	1.08	0.057	0.1062	0.038	0.24

NS $P > 0.05$, *** $P < 0.001$

2.7.4. Discussion

The choice-fed pigs discriminated between the feeds, but most did not select a mixture of the two feeds offered that would have met their tryptophan requirements. However, there was no relationship between weight gain and the tryptophan concentration consumed in the choice-fed pigs (Figure 2.19), but only one pig selected a very low tryptophan concentration. A further seven pigs consumed tryptophan concentrations below the asymptote of the growth curve found in the single-fed pigs of 8.2 g kg^{-1} digestible protein, but none of these pigs consumed less than 7.2 g kg^{-1} digestible protein. This suggests that the majority of the pigs met their minimum tryptophan requirements, although many pigs greatly exceeded this level. However, the growth curve for the single-fed pigs also suggests that there is little or no penalty to consuming diets with tryptophan concentrations above requirements at least up to 20 g kg^{-1} digestible protein.

Figure 2.19. Weight gain of individual choice-fed pigs consuming differing tryptophan concentrations.



2.7.5. Conclusion

The pigs did select feeds on the basis of their tryptophan concentrations. However, as with lysine and threonine, few pigs selected a blend of feeds which would have provided an appropriate tryptophan concentration.

2.8. Selection of a lysine or tryptophan solution by pigs fed diets of varying lysine or tryptophan concentration.

2.8.1. Introduction

In previous experiments in which growing pigs have been offered a choice of two feeds differing only in the level of one or two amino acids, they have not selected a mixture of the two feeds to meet their requirements, but have instead tended to eat one or other of the feeds offered. However, they did appear to be able to detect differences between two feeds differing in the concentration of one amino acid. This suggests that pigs may have the ability to regulate their amino acid intake, but prefer to eat from only one feed. To investigate this theory, growing pigs were given a single feed, with either a deficiency or an excess of lysine or tryptophan and were also allowed access to an alternate source of the same amino acid. In this experiment, the source of amino acid was a solution.

2.8.2. Methods and Materials

Two experiments were carried out, each including six dietary treatments, which were varying concentrations of either lysine or tryptophan and a choice of water and an amino acid solution.

(i) Lysine Experiment

Twenty-four male growing pigs, approximately nine weeks old and with an initial mean weight of 19.6 kg, were allocated at random to one of six dietary treatments, each consisting of a single feed. A basal lysine-deficient feed was formulated and supplemented with synthetic lysine to form six feeds with different digestible lysine concentrations. The composition of the low and high lysine feeds can be found in Table 2.6 on page 60.

1. Low lysine	25 g kg^{-1} digestible protein
2. Medium Low lysine	50 g kg^{-1} digestible protein
3. Intermediate Low lysine	62 g kg^{-1} digestible protein
4. Intermediate High Lysine	89 g kg^{-1} digestible protein
5. Medium High lysine	109 g kg^{-1} digestible protein

6. High Lysine 141 g kg^{-1} digestible protein

Pigs were given *ad libitum* access to the feed in two single space feeders in each pen. Water was available *ad libitum* from two troughs situated at the front of the pen (Figure 2.3, page 61, single-fed pigs).

All the pens in the experimental house were used. Treatments were allocated randomly to the pens in each block. All the pigs were weighed three consecutive days every week and a mean value calculated. Feed consumed was recorded for a three day and a four day period each week throughout the experiment.

For the first fourteen days of the experiment both water troughs contained water and the amount drunk from each trough was measured daily. After fourteen days one trough in each pen was filled with a lysine solution of 3.9 g $litre^{-1}$. The amount drunk from each trough was again measured daily for fourteen days.

(ii) Tryptophan Experiment

Twenty-four male growing pigs, approximately nine weeks old and with an initial mean weight of 18.9 kg, were allocated at random to one of six dietary treatments, each consisting of a single feed. A basal tryptophan-deficient feed was formulated and supplemented with synthetic tryptophan to form six feeds with different digestible tryptophan concentrations. The composition of the Low tryptophan feed can be found in Table 2.39 on page 157.

1. Low tryptophan	4.4 g kg^{-1} digestible protein
2. Medium Low tryptophan	7.2 g kg^{-1} digestible protein
3. Intermediate Low tryptophan	8.6 g kg^{-1} digestible protein
4. Intermediate High Tryptophan	12.5 g kg^{-1} digestible protein
5. Medium High tryptophan	15.0 g kg^{-1} digestible protein
6. High Tryptophan	20.3 g kg^{-1} digestible protein

Pigs were given *ad libitum* access to the feed in two single space feeders in each pen. Water was available *ad libitum* from two troughs situated at the front of the pen (Figure 2.3, page 61, single-fed pigs).

All the pens in the experimental house were used. Treatments were allocated randomly to the pens in each block. All the pigs were weighed three consecutive days every week and a mean value calculated. Feed consumed was recorded for a three day and a four day period each week throughout the experiment.

For the first fourteen days of the experiment both water troughs contained water and the amount drunk from each trough was measured daily. After fourteen days one trough in each pen was filled with a tryptophan solution of 2.8 g litre^{-1}. The amount drunk from each trough was again measured daily for fourteen days.

2.8.3. Results

(i) Lysine experiment

There was no difference between the initial mean weight for each treatment (Table 2.45). Weight gain was different between the treatments ($P < 0.05$) before the pigs had access to the lysine solution, weight gain increased with increasing lysinc concentration up to the intermediate Low lysine concentration then decreased to a constant about half the maximum. Feed intake was not significantly different between the treatments, but tended to be lower in the low, intermediate high and medium high lysine feeds. Feed conversion efficiency (FCE) was different between the treatments ($P > 0.01$) with a similar pattern to weight gain. Once the pigs had access to the lysine solution there were no significant differences between treatments in weight gain, feed intake or FCE; however, the pigs on the medium low and intermediate low lysine feeds tended to grow faster and eat more (Table 2.45).

The amount of lysine consumed was very different between the treatments before and after access was given to the lysine solution. However, after the pigs had access to the lysine solution they consumed at least 50%

TABLE 2.45. Effect of dietary lysine concentration on weight gain, feed intake and feed conversion efficiency before and after addition of lysine solution.

	Initial Weight (kg)	Before Addition of Lysine Solution			After Addition of Lysine Solution		
		Weight Gain (kg/day)	Feed Intake (kg/day)	Feed Conversion Efficiency	Weight Gain (kg/day)	Feed Intake (kg/day)	Feed Conversion Efficiency
Digestible Lysine Concentration (g/kg digestible protein)	NS	*	NS	**	NS	NS	NS
25	18.30	0.311	1.101	0.280	0.620	1.541	0.424
50	21.25	0.661	1.413	0.464	0.850	1.847	0.455
62	22.15	0.875	1.533	0.571	0.930	1.985	0.467
89	18.58	0.393	0.868	0.431	0.507	1.126	0.432
109	17.25	0.393	0.859	0.437	0.493	1.411	0.338
141	20.40	0.545	1.214	0.432	0.718	1.527	0.459
Mean	19.65	0.529	1.165	0.436	0.686	1.573	0.429
SEM (15 df)	1.549	0.0999	0.1665	0.0418	0.1306	0.2147	0.0604

NS $P > 0.05$, * $P < 0.05$, ** $P < 0.01$

more lysine than they had previously, and the pigs on the low lysine feed consumed three times as much lysine once they had access to the lysine solution (Table 2.46). Lysine concentration was fixed before the addition of lysine solution, and afterwards the pigs on the different treatments still consumed different lysine concentrations ($P < 0.001$). The largest rise in lysine concentration consumed occurred in the pigs on the low lysine treatment, and the smallest rise occurred in the pigs on the high lysine treatment (Table 2.46).

The proportion of liquid drunk from each trough did not differ between treatments, either before or after the addition of the lysine solution (Table 2.46 and Figure 2.20).

(ii) Tryptophan experiment

There was no difference between the initial mean weight for each treatment (Table 2.47). Weight gain was not significantly different between the treatments before the pigs had access to the tryptophan solution, however, the pigs on the low tryptophan treatment did tend to grow slower than the pigs on the other treatments. Feed intake was not significantly different between the treatments, but tended to be higher in

TABLE 2.46. Effect of dietary lysine concentration on amount lysine consumed, lysine concentration consumed and proportion of liquid drunk from the trough assigned to contain lysine solution, before and after the addition of lysine solution.

	Before Addition of Lysine Solution			After Addition of Lysine Solution		
	Lysine Consumed (g/day)	Lysine Concentration Consumed (g/kg DP)	Proportion Liquid Drunk From Trough With Lysine Solution	Lysine Consumed (g/day)	Lysine Concentration Consumed (g/kg DP)	Proportion Liquid Drunk From Trough With Lysine Solution
Digestible Lysine Concentration: (g/kg digestible protein)	***		NS	**	***	NS
25	4.7	24.7	0.551	14.5	55.7	0.555
50	12.6	50.4	0.564	26.4	80.2	0.549
62	16.6	60.2	0.545	32.0	89.1	0.542
89	14.5	89.6	0.507	25.2	118.5	0.506
109	18.0	109.2	0.544	35.8	132.2	0.538
141	34.3	140.8	0.544	52.1	169.9	0.565
Mean	16.8		0.542	31.0	107.6	0.542
SEM (15 df)	3.01		0.0199	4.75	2.89	0.0289

NS > 0.05, ** < 0.01, *** < 0.001

FIGURE 2.20. Proportion of liquid consumed from the trough assigned to contain lysine solution before and after the addition of lysine solution.

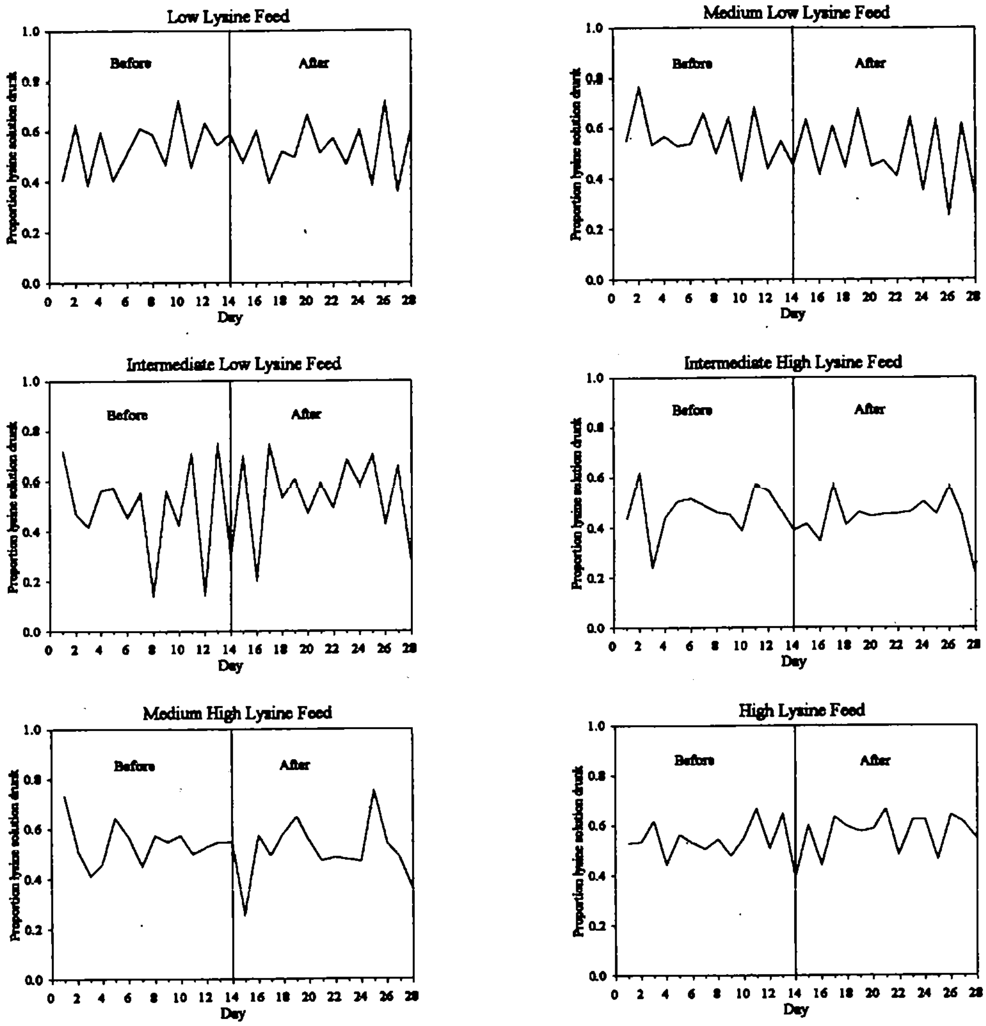


TABLE 2.47. Effect of dietary tryptophan concentration on weight gain, feed intake and feed conversion efficiency before and after the addition of tryptophan solution.

	Initial Weight (kg)	Before Addition of Tryptophan Solution Weight Gain (kg/day)	Feed Intake (kg/day)	Feed Conversion Efficiency	After Addition of Tryptophan Solution Weight Gain (kg/day)	Feed Intake (kg/day)	Feed Conversion Efficiency
Digestible Tryptophan Concentration: (g/kg digestible protein)	NS	NS	NS	NS	NS	NS	NS
4.4	19.08	0.179	0.855	0.210	0.571	1.516	0.381
7.2	19.17	0.352	1.235	0.286	0.595	1.751	0.348
8.6	18.75	0.370	1.050	0.349	0.445	1.562	0.289
12.5	17.75	0.311	1.005	0.316	0.534	1.674	0.316
15.0	19.60	0.337	1.008	0.336	0.561	1.550	0.361
20.3	19.15	0.341	0.876	0.375	0.570	1.452	0.389
Mean	18.92	0.315	1.005	0.312	0.546	1.584	0.348
SEM (15 df)	1.080	0.0567	0.1062	0.0383	0.0776	0.1817	0.0363

NS P > 0.05

the medium low and intermediate low tryptophan feeds. There was no difference in FCE between the treatments, although the pigs on the low and medium low tryptophan feeds tended to have a lower FCE. Once the pigs had access to the tryptophan solution there were no significant differences between treatments for weight gain, feed intake or FCE (Table 2.47).

The amount of tryptophan consumed was very different between the treatments before access was given to the tryptophan solution ($P < 0.01$ and $P < 0.001$). However, after the pigs had access to the tryptophan solution the amount of tryptophan consumed was not different between treatments. The pigs on the low tryptophan treatment consumed about thirteen times as much tryptophan as they did before they had access to the solution, while the pigs on the high tryptophan feed consumed less than three times as much tryptophan once they had access to the tryptophan solution (Table 2.48). Tryptophan concentration was fixed at different levels before the addition of the tryptophan solution; however, afterwards there was no difference between the tryptophan concentrations consumed by the pigs on different treatments (Table 2.48).

The proportion of liquid drunk from each trough did not differ

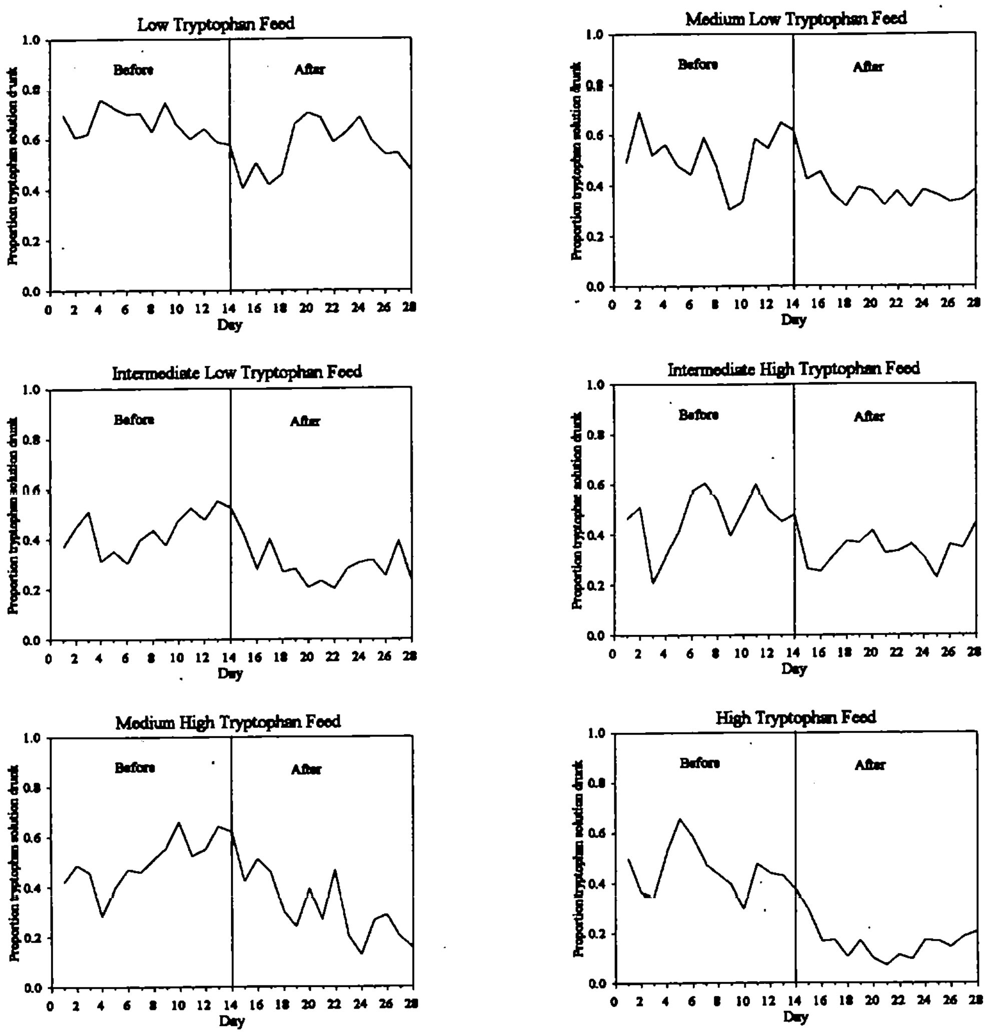
TABLE 2.48. Effect of dietary tryptophan concentration on amount tryptophan consumed, tryptophan concentration consumed and proportion of liquid drunk from the trough assigned to contain tryptophan solution, before and after the addition of tryptophan solution.

	Before Addition of Tryptophan Solution			After Addition of Tryptophan Solution		
	Tryptophan Consumed (g/day)	Tryptophan Concentration Consumed (g/kg DP)	Proportion Liquid Drunk From Trough With Tryptophan Solution	Tryptophan Consumed (g/day)	Tryptophan Concentration Consumed (g/kg DP)	Proportion Liquid Drunk From Trough With Tryptophan Solution
Digestible Tryptophan Concentration: (g/kg digestible protein)	***		NS	NS	NS	*
4.4	0.6	4.5	0.651	7.8	31.1	0.580
7.2	1.5	7.3	0.529	6.1	21.2	0.372
8.6	1.5	8.7	0.545	7.3	28.2	0.408
12.5	2.1	12.7	0.397	7.0	25.1	0.228
15.0	2.5	15.0	0.514	7.6	29.6	0.297
20.3	3.0	20.4	0.436	7.0	28.8	0.154
Mean	1.9		0.512	7.1	27.3	0.340
SEM (15 df)	0.24		0.1013	1.85	6.00	0.1201

NS $P > 0.05$, ** $P < 0.01$, *** $P < 0.001$

significantly between treatments before the addition of the tryptophan solution. After the addition of the solution there was a linear relationship between dietary tryptophan concentration and proportion of liquid drunk from the tryptophan trough, with a decreasing proportion drunk from the tryptophan solution with increasing dietary tryptophan concentration (Table 2.48 and Figure 2.21).

FIGURE 2.21. Proportion of liquid consumed from the trough assigned to contain tryptophan solution before and after the addition of tryptophan solution.



2.8.4. Discussion

In the first half of the experiments there was a growth response to increased lysine and tryptophan concentration, showing that the low lysine and tryptophan feeds were deficient. Once the pigs had access to an alternative source of lysine or tryptophan this growth response no longer occurred, since the pigs were able to utilise the soluble amino acid to offset the deficiency in thc feed. However, this resulted in all the pigs consuming a large excess of lysine or tryptophan, so it would appear that the pigs did not regulate precisely their amino acid intake in this way.

When rats were given a histidine-deficient diet and a histidine solution, they consumed enough of the solution for normal growth to occur (Rogers and Harper, 1970). However, chicks given a choice of a lysine-deficient or a lysine-free diet and crystalline L-lysine HCl did not consume enough lysine to support maximum growth (Newman and Sands, 1983), although they did grow considerably better and ate more than chicks on the lysine-deficient or lysine-free diets alone. Rats given a choice of eight solutions preferred the lysine solution least when they were given a control diet, but when they were given a lysine-deficient diet they preferred the lysine solution most (Tabuchi, Taketoshi, Nishijo and Torii, 1991). In another experiment, rats fed a lysine-deficient diet selected a lysine solution from among fifteen amino acid solutions (Torii, Mimura and Yugari, 1987). However, unlike the present experiment, these rats only consumed 1.4 times the expected amount of lysine.

In the tryptophan experiment the pigs did seem to discriminate between the tryptophan solution and the water, since the pigs on the feeds with lower tryptophan concentrations tended to drink a larger proportion of their total liquid intake from the tryptophan solution.

2.8.5. Conclusion

Pigs could detect lysine and tryptophan in solution, and pigs on diets deficient in these amino acids utilised these amino acid solutions to allow them to grow as well as pigs on diets with excess amino acid. When pigs were given tryptophan solution there was a degree of selection for the solution in that the higher the dietary tryptophan concentration the less solution the pigs consumed.

3. General Discussion

The original objective of this project was to discover if diet selection could be used to determine the ideal protein for pigs. The experiments in this project have shown that while there was an optimum level of individual amino acids in the diet of growing pigs and they could discriminate between feeds with differing amino acid concentrations, growing pigs did not select a mixture of two feeds, that differed only in amino acid concentration, to meet their amino acid requirements.

The single-feed experiments in this project demonstrated that there were relatively large differences between the productive performance of growing pigs fed different amino acid concentrations. The lysine and tryptophan single-feed experiments indicated that there was maximised growth at a particular dietary concentration of these amino acids. Weight gain, feed intake and feed conversion efficiency all increased to a maximum point with increasing amino acid concentration. After this point there was an immediate decrease in performance, which then stabilised at a more or less constant level. The increase in performance was due to the amino acid becoming less limiting in the diet, until it reached a point where it was no longer limiting. At this point another nutrient then became limiting and performance no longer responded to increasing amino acid concentration. Most studies carried out elsewhere do not offer pigs a wide enough range of amino acid concentrations to show a similar response to the experiments in this project, but these studies do tend to show performance increasing to a point and then beginning to decrease (Rogerson and Campbell, 1982; Lenis *et al*, 1990; Schutte *et al*, 1990).

The threonine single-feed experiment did not follow this pattern, instead both weight gain and feed intake were at a maximum at the lowest concentration of threonine, and feed conversion efficiency remained constant at all threonine concentrations. Perhaps the most likely explanation for this is that the threonine concentration of the most deficient feed was not limiting, and that the results of this experiment only represented the second part of the response to increased amino acid concentration, where performance is decreasing from the maximum level.

The results of all three individual amino acid single-feed experiments suggested that the optimum concentrations of these amino acids were lower than most current estimates (eg ARC, 1981). However, in the lysine and tryptophan experiments none of the feeds offered were close to the ARC (1981) recommendations, and had such a feed been offered it is possible that the maximum response may have been at a higher amino acid concentration.

The experiments in this project provided no evidence that growing pigs, although they had definite feed preferences, could select a mixture of two feeds to maximise growth. In the three choice experiments in this project involving a choice between two feeds that differed in a single amino acid, the majority of pigs on each treatment selected the feed which was the most appropriate for their requirements. Pigs could also discriminate between two feeds that differed in the concentration of two amino acids, and between feeds that differed in protein or protein and lysine concentrations. There were only two treatments out of a total of twenty-five dietary choice treatments in this project in which pigs did not discriminate between the two feeds.

This ability of pigs to discriminate between feeds with differing amino acid concentrations has also been shown in work carried out elsewhere. Henry (1987) found that pigs could discriminate between feeds with differing lysine concentrations. Other studies have shown that pigs can discriminate between feeds with differing methionine or lysine concentrations (Robinson, 1975). Devilat *et al* (1970) offered pigs the choice between a complete diet and a diet deficient in some amino acids, and the pigs chose mainly the complete diet. The pigs in this project could also detect amino acids in solution and discriminate between this and dietary amino acid concentrations.

The pigs in this project were not able to select a balance of feeds to provide an appropriate amino acid or protein concentration according to their requirements indicated in the single-feed experiments. They tended to eat one or other of the feeds offered, rather than selecting a mixture of the two feeds. This tendency was not affected by offering a choice of feeds differing in two amino acids; in these cases the pigs chose the one feed that they ate on the basis of the concentration of only one of the amino acids. When pigs were offered a choice of feeds that differed in protein concentration with balanced lysine, they did eat some of each feed; however, the resultant range of protein concentrations consumed was very large, so was very unlikely to reflect the pigs' requirements. When the same feeds were imbalanced for lysine the pigs again tended to eat only one of the two feeds offered. Feeder position preferences were seen when both feeders contained the same feed, but this did not affect the selections made when differing feeds were offered.

Diet selection experiments carried out elsewhere have concluded that pigs can select a mixture of two feeds to reflect their protein requirements. However, often the results from these experiments show that pigs do eat predominantly one feed.

Kyriazakis (1989) described an experiment in which all the pigs selected the low protein feed in the choices he offered them, and consequently did not grow as well as the single-fed pigs on the higher protein feeds. Most of the data from diet selection experiments are presented as treatment means, allowing little insight into individual pigs' selections. Kyriazakis *et al*, (1990) presented individual pig data for two treatments; in the first one, three out of the four pigs ate only one of the two feeds; the remaining pig preferred the higher protein feed, but did eat some of the lower protein feed. In the other treatment in which individual data was presented, all four pigs had a strong preference for the higher protein feed for the first few days of the selection period, although some pigs did then go on to eat some of both feeds.

Bradford and Gous (1991a) gave groups of ten growing pigs a choice between two feeds of varying protein concentrations, and in two of the six choices the pigs tended to eat only one of the feeds offered. When groups of ten weaner pigs were given a choice of two different protein sources, they had a tendency to avoid the plant-based protein in favour of the other food offered, even when this was a low protein feed (Bradford and Gous, 1992).

An important aspect of the results from pig diet selection experiments has been the ability of pigs to change their selections over time, thus reflecting their changing requirements (Kyriazakis *et al*, 1990; Bradford and Gous, 1991a). The meaned results of groups of pigs suggested that a mixture is selected and the proportions were changed in a similar direction to the change in their requirements, but this change often happened over a very short time period. For example, Kyriazakis *et al*, (1990) reported that the protein concentration selected by four pigs fell from 250 to 170 g kg^{-1} feed in just over two weeks. This can be compared with ARC (1981) recommended protein concentrations which remain the same for pigs of 20 to 50 kg, and with NRC (1989) recommended protein concentrations which are 180 and 150 g kg^{-1} for 10-20 and 20-50 kg pigs, respectively. This would suggest that the fall in selected protein concentration seen in the aforementioned experiment is much more rapid than the fall in requirements and may therefore not be a reflection of changing requirements, but of other stimuli. Similar large falls in selected protein concentration can be seen in other experiments (Kyriazakis *et al*, 1991; Kyriazakis *et al*, 1993).

The amino acid requirements of growing pigs, when expressed as a ratio to protein, would not be expected to change substantially over time. However, in the lysine experiment in this project, the pigs given a short training period did appear to select a changing lysine concentration. This change was due to pigs eating from both feeds at first and then changing to eat from only one feed; the gradual effect of the change was due to the fact that individual pigs started eating from only one feed at different times. Kyriazakis *et al* (1991) investigated training period length and found very similar results. Pigs were given either no training period, a training period of six days with access to one feed only (high or low protein) or a six day training period with access to both feeds on alternating days. Individual pig data are given for pigs with no training period and those on the alternating training period. The pigs with no training period tended to eat some of both feeds. Pigs with a six day alternating training period, offered the same choice of feeds as those pigs with no training period, tended to eat one feed from the start of the selection period (Kyriazakis *et al*, 1991).

Unfortunately, most pig diet selection experiments are carried out on groups of pigs (Stabler, 1911; Evvard, 1914; Lassiter, Terrill, Becker and Norton, 1955; Hutchison *et al*, 1957; Hillier and Martin, 1958; Thrasher *et al*, 1961; Engelke *et al*, 1984; Edmonds *et al*, 1987; Gous, Bradford and Kobus, 1989; Bradford and Gous, 1991a; 1991b; 1992) which means that selections made by individual pigs cannot be ascertained. It may also be true that pigs that are feeding in groups are more likely to eat from both feeds due to competition for feeder space and facilitated learning, as was seen in the protein choice experiment in this project. Despite this there is still some evidence that pigs fed in groups do have a tendency to eat from only or largely one feed when presented with a choice. Groups of pigs offered a choice of maize or a protein supplement also tended to eat mostly (up to 94%) the maize (Lassiter *et al*, 1955). Groups of ten growing pigs given a choice between two feeds of varying protein concentrations had a tendency to eat only one of the feeds offered in some treatments (Bradford and Gous, 1991a; Bradford and Gous, 1992). In the protein choice experiment in this project, pigs in a group of three tended to eat only the higher protein feed offered.

A review of diet selection experiments carried out on rats (Galef, 1991) pointed out that there have been as many apparently unsuccessful experiments as there have been successful experiments, but that unsuccessful experiments have largely been ignored. The review suggests that differences between food preferences and food sampling patterns of individuals or the particular foods offered in an experiment could explain the contradictory results between experiments and even within experiments.

Thus, from evidence of recent pig and rat diet selection experiments and from the experiments in this project, it would appear that these animals are not able to consistently select a mixture of two feeds to meet their requirements.

4. General Conclusions

(i) The productive performance of growing pigs did respond to increasing amino acid concentration until it was maximised at a particular amino acid concentration.

(ii) The diet selection techniques used in this project were not suitable for determining the ideal protein for growing pigs.

(iii) Growing pigs could discriminate between two feeds that differed in the concentration of a single amino acid, and selected the one feed that was most appropriate for their requirements. Growing pigs could also discriminate between two feeds that differed in protein concentration, the concentration of two amino acids and in the concentration of a single amino acid and protein.

(iv) Growing pigs could not select a mixture of two feeds differing in protein or amino acid concentration to accurately reflect their requirements, they tended instead to eat one of the two feeds offered.

(v) An increased training period length reduced individual variation during the selection period.

(vi) Varying both protein and lysine concentration did not affect the pigs tendency to eat only one of the feeds offered.

(vii) Preference for a particular feeder position did not affect the selections made by growing pigs.

(viii) Growing pigs could detect amino acids in solution, and pigs fed amino acid deficient diets showed a crude preference for the amino acid solution.

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Appendix A. Selection of dietary lysine concentration by growing pigs with differing training period lengths.

TABLE A1. Effect of dietary choice treatment on weight gain, feed intake and feed conversion efficiency of pigs with an eight-day training period.

	Initial Weight (kg)	Weight Gain (kg/day)	Food Intake (kg/day)	Feed Conversion Efficiency
Choice:	NS	NS	NS	NS
High + Low	10.88	0.408	1.045	0.386
High + Medium Low	12.10	0.571	1.365	0.414
Medium High + Low	12.02	0.423	1.026	0.414
Medium High + Medium Low	10.10	0.435	1.079	0.395
Mean	11.27	0:459	1.129	0.402
SEM (18 df)	1.076	0.0618	0.1184	0.0263

NS $P > 0.05$

TABLE A2. Effect of dietary choice treatment on the amount of digestible lysine consumed by pigs with an eight-day training period.

	Digestible lysine consumed (g/day)			
	Days 1-4 of selectior	Days 5-7 of selection	Days 8-11 of selection	Days 12-14 of selection
Choice:	NS	NS	NS	NS
High + Low	19.2	15.3	27.1	24.1
High + Medium Low	18.7	13.9	17.6	23.3
Medium High + Low	14.0	13.4	23.0	17.8
Medium High + Medium Low	15.8	13.7	18.1	16.0
Mean	16.9	14.1	21.5	20.3
SEM (18 df)	4.05	3.32	4.17	2.71

NS $P > 0.05$

TABLE A3. Effect of dietary choice treatments on the digestible lysine concentration consumed by pigs with an eight-day training period.

	Digestible lysine conc. (g/kg digestible protein)			
	Days 1-4 of selection	Days 5-7 of selection	Days 8-11 of selection	Days 12-14 of selection
Choice:				
High + Low	93.8	91.1	120.7	113.8
High + Medium Low	75.6	72.2	67.1	75.4
Medium High + Low	78.0	80.6	93.2	75.4
Medium High + Medium Low	75.1	78.4	82.5	98.1
Mean	80.7	80.6	90.9	92.1
SEM (18 df)	10.46	12.58	10.46	10.86

TABLE A4. Effect of dietary choice treatments on the proportion of higher lysine feed consumed by pigs with an eight-day training period.

	Proportion of higher lysine feed selected			
	Days 1-4 of selection	Days 5-7 of selection	Days 8-11 of selection	Days 12-14 of selection
Choice:				
High + Low	0.582	0.562	0.817	0.753
High + Medium Low	0.268	0.233	0.180	0.267
Medium High + Low	0.615	0.644	0.797	0.863
Medium High + Medium Low	0.410	0.469	0.542	0.516
Mean	0.464	0.473	0.574	0.593
SEM (18 df)	0.1257	0.1451	0.1378	0.1344

TABLE A5. Effect of dietary choice treatments on weight gain, feed intake and feed conversion efficiency of pigs with a fourteen-day training period.

	Initial Weight (kg)	Weight Gain (kg/day)	Feed Intake (kg/day)	Feed Conversion Efficiency
Choice:	NS	NS	NS	NS
High + Low	15.60	0.604	1.277	0.457
High + Medium Low	14.57	0.726	1.711	0.442
Medium High + Low	14.88	0.625	1.344	0.470
Medium High + Medium Low	18.02	0.792	1.764	0.448
Mean	15.77	0.687	1.524	0.454
SEM (9 df)	1.038	0.0841	0.1887	0.0296

NS $P > 0.05$

TABLE A6. Effect of dietary choice treatments on the amount of digestible lysine consumed by pigs with a fourteen-day training period.

	Digestible lysine consumed (g/day)					
	Days 1-4 of selection	Days 5-7 of selection	Days 8-11 of selection	Days 12-14 of selection	Days 15-18 of selection	Days 19-21 of selection
Choice:	NS	NS	NS	NS	NS	NS
High + Low	34.4	36.8	30.3	38.3	34.8	37.4
High + Medium Low	17.8	20.4	22.5	26.6	36.3	36.8
Medium High + Low	23.1	23.7	30.2	26.7	28.6	34.3
Medium High + Medium Low	20.6	20.2	19.9	30.9	25.7	35.2
Mean	24.0	25.3	25.7	30.6	31.4	35.9
SEM (9 df)	3.94	4.53	5.57	7.07	8.77	8.60

NS $P > 0.05$

TABLE A7. Effect of dietary choice treatments on the digestible lysine concentration consumed by pigs with a fourteen-day training period.

	Digestible lysine concentration (g/kg digestible protein)					
	Days 1-4 of selection	Days 5-7 of selection	Days 8-11 of selection	Days 12-14 of selection	Days 15-18 of selection	Days 19-21 of selection
Choice:						
High + Low	134.8	134.4	139.1	139.9	140.0	134.9
High + Medium Low	66.8	68.9	71.2	75.0	88.9	78.2
Medium High + Low	106.5	89.6	108.8	102.6	109.2	106.3
Medium High + Medium Low	82.1	85.5	72.2	76.9	77.3	70.6
Mean	97.5	96.4	97.8	98.6	103.8	97.5
SEM (9 df)	4.84	10.73	10.43	11.79	13.19	10.66

TABLE A8. Effect of dietary choice treatments on the proportion of higher lysine feed selected by pigs with a fourteen-day training period.

	Proportion of higher lysine feed selected					
	Days 1-4 of selection	Days 5-7 of selection	Days 8-11 of selection	Days 12-14 of selection	Days 15-18 of selection	Days 19-21 of selection
Choice:						
High + Low	0.941	0.938	0.984	0.962	0.993	0.943
High + Medium Low	0.166	0.202	0.228	0.265	0.419	0.302
Medium High + Low	0.964	0.978	0.994	0.914	1.000	0.961
Medium High + Medium Low	0.527	0.409	0.367	0.447	0.455	0.340
Mean	0.649	0.632	0.644	0.647	0.719	0.636
SEM (9 df)	0.0766	0.1365	0.1360	0.1649	0.1733	0.1379

Appendix B. Determination of serum triglyceride and ß-hydroxybutyrate concentrations.

Triglycerides

Serum triglyceride concentration was determined using a Sigma Diagnostics kit (No. 334-UV).

Triglycerides are hydrolysed to glycerol and fatty acids by lipase. Glycerol is then phosphorylated by ATP to produce glycerol-1-phosphate in a reaction catalysed by glycerol kinase (GK). ATP is then regenerated when phosphhoenol pyruvate becomes pyruvate, catalysed by pyruvate kinase (PK). Pyruvate is then reduced to lactate in the presence of lactate dehydrogenase (LD), with simultaneous oxidation of equimolar amounts of NADH, which absorbs at 340 nm. The decrease in absorbance at this wavelength is directly proportional to the triglyceride concentration in the sample.

$$\text{Triglycerides} \xrightarrow{\text{Lipase}} \text{Glycerol} + \text{Fatty Acids}$$

$$\text{Glycerol} + \text{ATP} \xrightarrow{\text{GK}} \text{Glycerol-1-Phosphate} + \text{ADP}$$

$$\text{ADP} + \text{Phosphoenol Pyruvate} \xrightarrow{\text{PK}} \text{Pyruvate} + \text{ATP}$$

$$\text{Pyruvate} + \text{NADH} + H^+ \xrightarrow{\text{LD}} \text{Lactate} + NAD^+$$

β-Hydroxybutyrate

Serum ß-hydroxybutyrate concentration was determined using a Sigma Diagnostics kit (No. 310-UV).

ß-hydroxybutyrateis oxidised to form acetoacetate, in a reaction catalysed by ß-hydoxybutyrate dehydrogenase (ß-HBDH). During this reaction an equimolar amount of NAD is reduced to NADH, which absorbs light at 340 nm. The increase in absorbance at 340 nm is directly proportional to the ß-hydroxybutyrate concentration in the sample.

$$\text{ß-hydroxybutyrate} + \text{NAD} \xrightarrow{\text{ß-HBDH}} \text{Acetoacetate} + \text{NADH}$$